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AN INQUIRY

INTO THE OPERATION OF

RUNNING STREAMS AND TIDAL WATERS,

WITH A VIEW TO DETERMINE

THEIR PRINCIPLES OF ACTION:

AND AN APPLICATION OF THOSE PRINCIPLES TO THE

IMPROVEMENT OF THE RIVER TYNE.

BODLEIANA BIBLIOTHECA

BY

THOMAS JOHN TAYLOR.

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TO

HIS GRACE THE DUKE OF NORTHUMBERLAND,

THIS ESSAY ON THE

IMPROVEMENT OF THE TYNE,

WHICH, FROM ITS SOURCE TO THE SEA, PASSES SO EXTENSIVELY THROUGH

HIS GRACE'S POSSESSIONS;

AND IN DEVELOPING WHOSE NAVIGABLE FACILITIES HIS GRACE

EVINCES SO MUCH INTEREST AND KNOWLEDGE,

IS, WITH PERMISSION, RESPECTFULLY DEDICATED, BY HIS GRACE'S

VERY OBLIGED AND OBEDIENT SERVANT,

THE AUTHOR.

The improvement of the Tyne is a topic so much agitated of late, that it might seem, there can hardly remain an opening for its further discussion. It is, however, an irksome, and not always a satisfactory task, to gather results from masses of evidence, often of a contradictory character, and from which, as well as from other sources, we fail, perhaps, at last, to elicit fixed rules or principles, enabling us to substitute fact and certainty for conjecture or opinion.

It is for the purpose of inquiring whether such fixed principles do really exist, and if so, in what manner they admit of a practical application, that the following essay has been written.

The views advanced are illustrated by diagrams, and, it is hoped, are explained with sufficient clearness to render further prefatory remarks unnecessary.

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IMPROVEMENT OF RIVERS.

CHAP. I.

Introductory—Materials of River Beds.

When the people of Mesopotamia were desirous to reduce the ravages occasioned by the inundations of the Euphrates, it appeared to them the most natural course to withdraw a portion of the water from the main current; and so they cut another channel trending westward from the banks of the great river. The effect was exactly the reverse of what had been anticipated. The current, weakened by division, was no longer able to carry forward its debris; and not only the bed of the new cut, but also that of the Euphrates itself, were ultimately silted up. Further mischief ensued. As the banks of inundating rivers are, for reasons which will be given in the sequel, higher than the general level of the adjacent grounds, the waters overflowed, and converted the south-western portion of the country into a pestiferous marsh, from which the poison wind, the Bade Simoom, blows to this day up the great valley, laden with disease and death.

Many ages after the foregoing specimen of river engineering had so signally failed, a discussion arose on a similar subject in the Roman Senate. The overflowings of the Tiber were much complained of; and it was thought, that by cutting off a part of the sources of supply, those inundations might be materially lessened in frequency, or altogether prevented. Plans were, therefore, devised for connecting the

Tiber with the Arno on one side, and the Nar on the other The people of Florence opposed the project, on the alleged ground that their city would be injured by drawing off into its river the superfluous waters of the Tiber; and the provincialists of the Nar were equally hostile, for similar reasons. The Senate, thus placed in a difficulty, adopted the advice of Piso, who stated that "Nature had known how to provide for our wants much better than Art, in assigning to rivers those springs, courses, boundaries, and limits, which were the most apposite." And so the matter dropped for the time. A modification of the scheme was, however, carried out under the Emperor Nerva, but the expected result entirely failed to be realized. Pliny relates that the canal made by order of that Emperor to draw off the superfluous waters of the Tiber, at the time of the greatest freshes, did not contribute in the smallest degree to prevent the inundations.

Piso's advice implied the adoption of a choice of evils. A sounder maxim would be, that in dealing with rivers, there are two modes of proceeding, by one of which we may second the operations of Nature, just as by the other we may thwart those operations. A countryman of Piso's, Emilius Scaurus, interpreted Nature more hopefully, and at the same time more justly, when, by a proceeding exactly the reverse of those described in the two foregoing cases, he united the various branches of the Po, near Parma and Placentia; and the joining of the whole in one channel, by concentrating the action of the river, caused the deepening of its bed to such an extent, that level was procured to drain the marshes of the neighbouring country.

But in drawing the line between Nature and Art, a great deal of circumspection is requisite. If the receptacles of rivers were rigid and uniform, like a cast-iron pipe, we might then determine, with considerable accuracy, the laws of their motion and resistance. No such uniformity, however, exists: on the contrary, the beds of rivers are shifting and fluctuating; they are composed, in different places, of different materials, such as gravel, sand, or rock, and they have very variable degrees of slope or fall. Again, with a certain volume of water, the bed is stable, while, with a greater volume, it is the reverse. In short, new terms of power as well as of resistance, continually occur for investigation, according to the variable nature of the circumstances alluded to; and rivers have thus the distinction of being not merely obedient to laws, *but of being governed, to a great extent, by those of their own creation.* Fully to appreciate those laws is an operation requiring the introduction of so many elements, that, for the present, we must be contented to regard the question as a physical rather than a mathematical one. The results of mere theory afford us scarcely any help, and are even, in many instances, at variance with the truth; thus, according to them, the motion of rivers ought to be swiftest at the bottom, while it is really the contrary: the velocity should go on increasing towards the outfall—yet the fact is not so: and by theory there should be no deviations from a straight line—yet rivers are proverbially meandering in their course.

Upon these and other difficult topics, the Italians, the modern restorers of river engineering, were in high dispute in the 16th century. Fontana, in 1598, observing that the entire waters of the Tiber during a great flood were confined within the arches of the Bridge of Quatro-Capi, in a section much smaller than that of the current, either before it reached, or after it left the bridge, came to the conclusion, that in order to admit of this contraction, the water must be *compressible.* But Castelli, in the early part of the 17th century, explained this circumstance correctly, by shewing, that where the section was reduced, a greater velocity ensued; and the same observer was the first who determined with anything like precision, the quantities of flowing waters, by multiplying together the sectional areas and velocities.

From this sample, we may judge of the state of hydrography at an epoch nearly five hundred years later than the building of old London Bridge, and may well excuse Peter of Colechurch for his ill calculation of the water-ways in that ancient structure.

The old errors were revived by the Italians. Guglielmini relates, that in the beginning of the 17th century, the River Lamone entered the Po di Primaro, near the town of St. Albert, from which place it was afterwards diverted, and made to enter the Adriatic by itself. "The consequence is," adds that author, "that the bed of this river has been so much raised, as to render it, at this day, opposite St. Albert, higher than the surface of the flood waters of the Po; therefore its own floods are so much higher than before, and require corresponding embankments to defend the adjacent lands." From the fact here recorded, he draws the direct inference, that if the Po were divided into a number of streams, equal to that of the Lamone, precisely the same result would happen to the former as has done to the latter. Another step in the same train of inference, leads to the conclusion, that *if the currents of undivided rivers be permitted to waste their energies on shoals and other obstructions of the bed, the result is, pro tanto, similar to that of withdrawing a portion of water.* Neither does Guglielmini omit to notice this very circumstance, for he says; "If we restrict the bed of a river by Art, we cause it to deepen its bed; while if the bed be too wide, or divided into several branches, its bottom will be raised in proportion."

Guglielmini's doctrines, to which we may add Castelli's, were not universally adopted. It was a plausible and common sense like view of the matter to conclude, that by withdrawing water from a stream, the tendency to inundation further down would be lessened: and Castelli himself says: "Considering the thing simply, and at the first appearance, it seemeth that none can think otherwise;" but then, those who rest here close their investigations too soon; the effect of withdrawing a portion of the stream is to diminish its velocity and corresponding power of excavation, and so, in the words of the same sagacious authority, "There is begat in the channel of the river a certain ridge or shelf;" in other words, the bottom of the river is raised.

The Italians have not left us any perfect works. They took rivers as they found them, and did not interrogate Nature why they were thus established; nor consequently did they employ means to render their own operations of secure and permanent advantage. We shall find that the mere application of an isolated principle, though sound in itself, is not sufficient, unless sustained by a number of corresponding details, the object of which is to maintain the altered order of things. And thus the adoption of a principle obliges us to frame a system in support of that principle.

If we follow the course of a river of sufficient magnitude from its source towards the sea, we shall find the bed over which it flows composed of very variable materials. Towards the head of the river the bottom consists of large stones, imperfectly rounded by the action of the current, and becoming larger and more angular the more nearly we approach the hills where the first springs originate. Frequently it happens that rivers, already of considerable volume, have a long course among the mountains, in which case the gravel of the extreme source is replaced by that of tributaries which enter further down; so that, as a general rule, large and angular stones are found in the beds of rivers so long as they continue to traverse the hill country, of whose fragments, in fact, the beds are formed, and with whose geological character they coincide. The border hills at the head of North Tyne are chiefly masses of sandstone, and in the Kielder and the Tyne we find accordingly the ruins of that rock formation, with a scanty admixture of other kinds of stone, derived mostly from the more ancient alluvions of the country. Some miles further down fragments of limestone are mixed with the sandstone gravel; then the Reid brings in, with its sandstones and limestones, pebbles of the characteristic trap rocks of the Cheviot range: the great whin sill afterwards contributes its proportion of basaltic pebbles. South Tyne brings in the ruins of the carboniferous lime rocks, and portions of the metalliferous veins of the lead measures. From Hexham to Stocksfield the river flows through the grit rocks which form the bottom lining of the Newcastle coal formation; eastward, as well as westward of Newcastle, the coal seams have been worked under its bed; and the formidable "Black Middens" are the fragments of a sandstone stratum forming the roof of the Bensham seam, which is being worked at Percy Main Colliery, at the depth of 160 fathoms from the surface. The magnesian lime strata are grazed, as it were, by the river just before it enters the North Sea.

Besides the various rock formations which are thus intersected by the Tynes and their tributaries, there are scattered, over the general surface of the basin, masses of alluvium of more ancient date, perhaps, than the river itself: but which, for our present purpose, may be classed in the same category with the other materials that find their way into its bed, though they often differ entirely in character from the true rocks of the country, and would tend to cause no little confusion in attempts made to judge of the geological structure of the interior from observations made in the last reaches of the gravels. Amongst the gravel at Newburn are found specimens of most of the primary rocks, none of which are to be found in their original state within the compass of the river basin. Yet, from their general hardness, they might, not improbably, in such a situation, form the predominant material, after the softer fragments of those strata which really constitute the rocks of the country, have been worn away.

Gravel, though very large and angular near the sources of rivers, becomes much smaller and more rounded in their lower reaches, and at length disappears from the beds of those rivers which have a sufficient length of course to enable it to do so. In this manner the proper gravels of the Tyne may be regarded as ceasing below Newburn, the rest of the course of the river being upon sand, with some adventitious gravel brought in by tributaries which enter further down. I am not here speaking of gravel which has been thrown into the river.

But the question arises, in what manner does gravel disappear from the beds of rivers ? It is assumed to be worn away by attrition : a position adopted by the writer ; with this qualification, however, that the time required to wear down the gravel is longer than has been usually assigned. Of the truth of the doctrine that gravel disappears by attrition, we may be convinced on abstract grounds ; for, allowing the detention of any one portion in the river, we must then grant the same of a second, and then of a third, until the conclusion is established, that river beds are in the course of being choked up, which is contrary to the fact.

Yet the doctrine that large stones become small ones by the action of river currents has been often repudiated ; and by some the inadequate notion has been maintained and even acted upon, that gravels might be retained in the upper parts of a river by throwing dams across it. Frisi, who ought to have known better, asserted, that large stones remained always in the upper courses of rivers, although the experiments related by him tend to a contrary conclusion. The stones in the Italian rivers are chiefly calcareous, being derived from the limestone formation of the Appenines. Of these stones he took forty, "white and gray, large and small," and caused them to be triturated, by a man, in a wooden box, well closed : after 2 hours he procured 2 ounces of dust, the weight of the stones having been originally 504 ounces. At the same rate of disintegration it would have taken 21 days entirely to pulverize the stones; "a much longer period," he adds, "than would be required for rivers running at the rate of four or five miles an hour to transport the substances they carry from the first springs to the utmost limits of their gravels;" and here lies the error of this learned Barnabite, whose experiment, in reality, proves nothing except that stones may be ground to powder by trituration in a box: he assumed, what is very far from being the fact, that all the materials of a river bed travel as fast as the flood current; whereas stones shifted from a particular point are probably laid down again at the next expansion of the current, or even before they reach that expansion. Neither does the smaller gravel travel fast, for it is sheltered by the heavier stones, and the friction during floods must be regarded as an average due to all the fragments on the bed, since the smaller and larger are so mixed together that they must move together; the whole bed must be considered as endued with one movement; and the motion of the whole bed down stream is very slow; yet slow as it is, it measures the rate at which gravel travels down the river. Sand only and mud are carried fast down; and even sand, in favourable situations takes a *set* upon the bottom, which renders it much more difficult to be moved than would be the case if its separate particles had to be drifted.

It is thus that we discover the principal agent in the reduction of gravels to be *Time*—time not of days, nor of years, but it may be of centuries. The largest stones in a river bed undergo a kind of burying process, the nature of which is easily understood; for, during floods, when the other parts of the bed are in motion, the larger masses continue at rest; and thus sink into a kind of hollow, which is filled up again as the flood subsides; in this situation they lie, for the most part, at an angle, the elevation of which is down stream; for the materials sheltered by them form a support to the lower end, while, at the upper one, they have been scooped out.

Large stones thus rooted may lie in river beds for generations without changing their place.

The materials, being thus worn away by slow attrition, we may next enquire into the distance required for the completion of this process; and on this part of the subject it is best to consult rivers themselves: it must also be borne in mind that as the tributaries of a river bring in gravel, we must not compute from the highest source of the waters the space required to wear down that material. Such observations cannot, therefore, be made with precision in all rivers: but if one can be found which bears from its source a gravel of a marked geological character, and which receives none of a similar kind afterwards, then such a river furnishes superior means of observation. The Coquet, in Northumberland, possesses this property: it issues from the Cheviots, and transports gravel derived from the trap rocks of these border hills. Close to the outfall of the river, between Warkworth and Amble, depositions of this gravel are to be found, the fragments of which rarely equal a pigeon's egg in size. Now the distance from Alwinton, where the Coquet issues from the lesser Cheviots, to Warkworth, is 31 miles, including the windings of the river, while the direct distance is 22 miles.

This is a good example for gravels, which may be put into the hardest class of those found in river beds; for in this respect there is a great deal of difference; the cohesive quality of stones, from the most refractory of the primary rocks, to the very friable sandstones, ranging as 60 to 1. When the derivative rock is softer, a much shorter distance may reduce the gravel: it is indeed surprising to observe in how small a space the less indurated materials become reduced in size. At the head of Bewshaugh, in North Tyne, the gravel is composed of lumps of sandstone, as big or bigger than one's head: yet at the foot of the haugh, no fresh accession of gravel having come in, the fragments are less than a fourth of the size: the distance is about a mile and a half. Lower down very large gravel is again brought in by the tributaries.

The Coquet is an example of a river which carries its gravel to the outfall; and there are many of a similar kind. The Tyne is not, however, properly a river of this character, because it ceases to carry the gravel of its upper course at the great Lemington bend. From this point to the limestone (a very hard rock), the distance is 23 miles by the winding course of the river; and to the whin sill is 26 miles. But the Tyne has tributaries which bring in gravel much nearer the sea than this apparent limit, though not in great quantities, there being no adjacent mountain range, the breaking down of which would afford a larger supply than that now derived mainly from the washing out of the pebbles contained in the ancient alluvial depositions.

The last limits of the gravelly bottom, and the beginning of the sandy one, are not always clearly defined; and an alteration may even take place in them under particular circumstances. For instance, a short cut made at the terminus of the gravel with a view to relieve a bend in the river, has been known, by the additional rate of fall thus occasioned in the bed, to carry the gravel three or four miles further down, and so it is possible that in improving rivers conflicting principles may at times come into operation, obliging us to pause before adopting the course which, under ordinary circumstances, is the most advisable to be pursued. Neither must principles be pushed too far. The gravel does not all stop at a particular line, but a portion is carried further on, and becomes mixed with the prevailing sand; in this situation it disappears, where sand can rest, by a burying process similar to that already described. The gravel is brought to the spot by floods, and is afterwards covered over by sand, when the slackening of the current permits that material to be deposited.

The origin of gravel may thus be traced to the rock formations intersected by rivers, and to the ancient alluvions occupying the surface of the countries over which they flow. To the sand which occupies their lower reaches, we may, for our present purpose at least, assign the same double origin. Those who are acquainted with the extensive decompositions and disintegrations of the secondary sandstone strata where they appear at the day, will not be at a loss to comprehend the origin of sand, even independently of that which may be produced by trituration in rivers, or of that of older alluvial depositions. There is also another class of rocks, the fragments of which soon disappear in the river bed, and form a portion of the mud which is suspended in its current: these are the soft shales, interstratified with the harder beds, and constituting, in fact, masses of indurated clay.

While on this part of the subject, it is right to mention an obvious inference from the foregoing details. If there were an annual accession of materials to the beds of rivers, without any being withdrawn, then it is clear that the beds must be choked up: for, taking the yearly quantity brought in, and multiplying it by 100, or 1,000, we shall presently arrive at a product representing those "Montagni di Sassi," "mountains of stones," alluded to by Guglielmini. Now the contrary is the fact: river beds not only maintain themselves open, but, as a general rule, become more depressed in level. We cannot, then, under these circumstances, get over the conclusion, that the materials carried into river beds are again withdrawn from them; and as the sea is the only ultimate receptacle, it follows, that in whatever shape the materials enter a river, they are, and must be, at last carried out to sea. And this proposition is, on the grounds stated, universally true, whether applicable to the largest fragment of rock, or to a grain of sand; the real question involving no more than the period of time, more or less protracted, required for the transmission of a particular material. Neither do deltoid rivers from an exception to this rule, because they undergo physical changes which oblige them, as we shall see, to raise their beds towards the interior, while, in other respects, they are confirmatory of the inference drawn, the magnitude of their deltas being an index of the quantity of materials transferred from the land to the sea.

From the same line of reasoning it follows, that though great quantities of marine sand are brought into the lower reaches of rivers, yet the account current, as we may call it, between the river and the sea, must have a balance in favour of the river, of materials carried out, over those received into, its tidal basin.

CHAP. II.

Fall of River Beds—The Flood State, the really Governing State of Rivers—Pools and Streams—Elementary forms of River Beds—The various Actions all traceable back to a Vertical Action—Actions on the Bottom and on the Banks, are alternate Actions.

We have seen that the coarse and heavy materials of the upper branches of rivers become gradually finer as they advance on their downward course; and we are now to contemplate a change of an equally notable character, accompanying this reduction in the size of materials. The declivity of bed is much greater towards the source of rivers than it is further down—a circumstance palpable enough to common observation. The *Torrent* trenches its mountain almost perpendicularly: the *Torrent River* receiving the torrent has already flowed some distance among the hills, and has flattened its bed considerably, but still possesses a great deal of fall: further on, we arrive at a stage of the river where the angular fragments of gravel have disappeared, and those found in the bed are rounded and much reduced in size: this is the river with a proper *gravelly bed*, whose fall is a good deal less than that of the torrent river. The fourth and last stage is that of the *sandy bed*, whose fall is very moderate, and in the case of first class rivers, hardly appreciable.

In the manner described there is established a succession of inclined planes, which, constantly diminishing in their rate of fall, constitute the beds of rivers on their progress towards the sea: the entire extension of bed has been, therefore, compared to an asymptotic line, which, though always approaching another line, yet never becomes exactly coincident with the latter: the resemblance, however, like the most of our attempts to measure nature by rule and scale, fails in being quite exact, since the line is disturbed by various local actions, and, if accurately adjusted to all the variations occasioned by tributaries, changes of course, and of geological formation, would present an irregular and serrated outline.

The truth, however, of the general proposition, that *the coarser the materials of a river bed, the greater is its rate of fall,* is a manifest consequence of the relation between cause and effect. A certain declivity is established, because the current cannot, without the help of that declivity, press forward the materials that encumber its bed. The heavier the materials, therefore, the greater the fall, and *è contra,* the lighter the materials the less is the fall. We may here refer to the fact.

	FEET PER MILE.
The fall of the Reid, from the foot of the Carter to Woodburn, is 422 feet in 18½ miles, being an average of	22·7
In the last 4 miles to Reidsmouth it is 60 feet, equal to	15·
The fall of North Tyne, from Reidsmouth to the confluence with South Tyne, 14 miles, is	13·
The fall of South Tyne, from Haltwhistle to the confluence, 17 miles, is	14·5
The fall of the Tyne, from Hexham to Stocksfield, 9 miles, is	7·
The fall of the Tyne, from Stocksfield to Ryton, the limit of the tidal flow, 7½ miles, is	3·8

It will be recollected, that the rates of fall are not uniformly distributed over the several distances, but become less towards the lower ends, as they are greater in approaching the upper ones. The levels I have deduced from those of the Newcastle and Carlisle Railway, and of the projected Newcastle and Glasgow Direct Railway: the distances include the windings of the river. In *Fig.* 1 the levels and distances are shewn at one view.

It is usually considered, that rivers cease to carry gravel when their slopes are less than 30 inches to a mile, and that

Fig: 2.

Reference to Fig. 2.

The Roman Numerals shew the relative Volumes of Water in each Stream.

The Common Numerals shew the Slopes in English Inches to an English Mile.

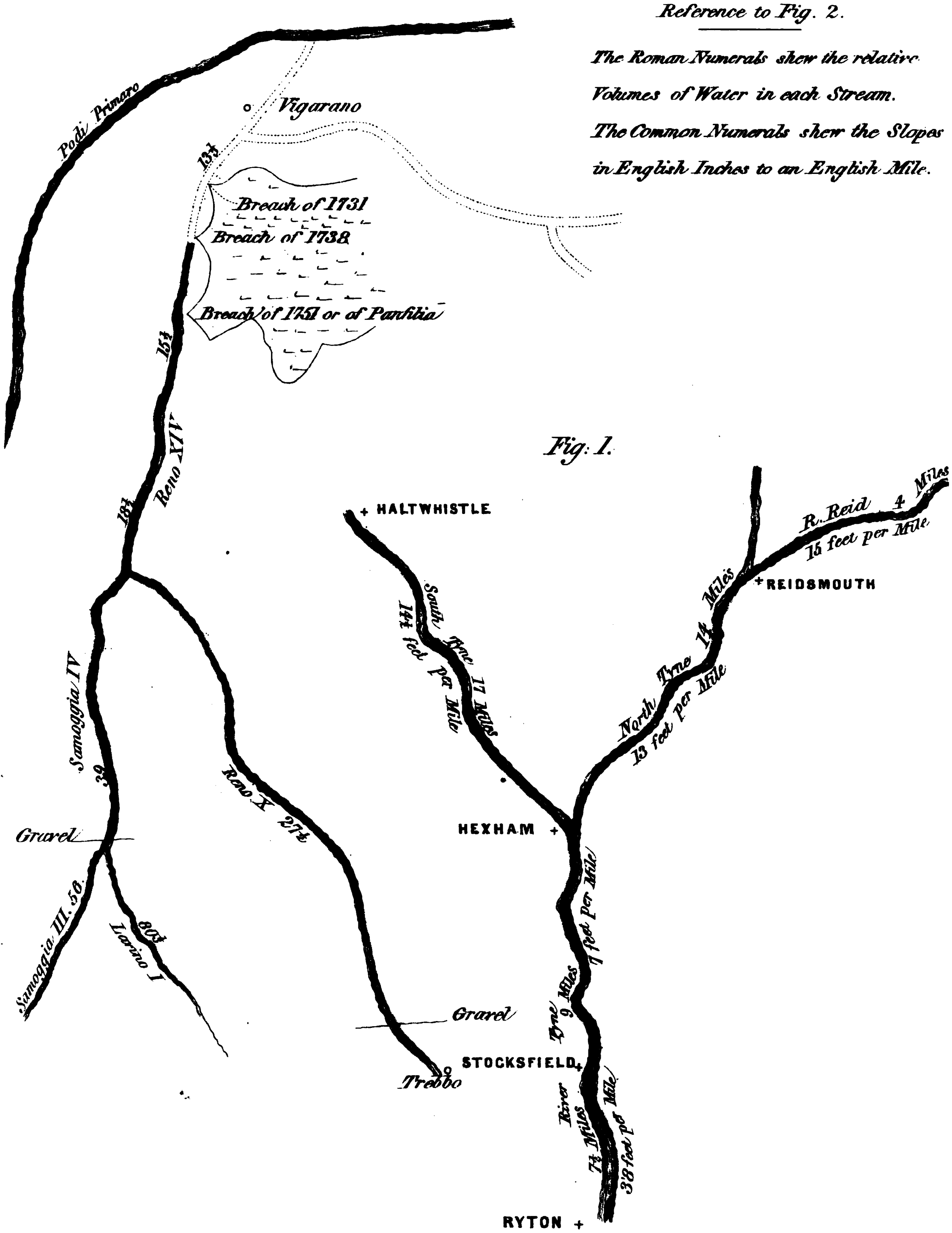

Fig: 1.

they then also become navigable for sailing vessels; but the reader must not allow himself to be governed by a generalisation of this kind. We shall see afterwards that large rivers may have a less fall, and yet a greater rapidity of current, than small ones. As a matter of fact, the rates of fall of rivers with sandy bottoms vary from 28 or 30 inches in a mile, down to Zero; for rivers of very large volume may flow without any declivity of bed, by raising their ulterior waters until the requisite propelling force, or *vis à tergo*, is established, and in this case there is a fall of the surface without any fall of the bed.

For the purpose of comparison, it may be stated that the fall of the Tweed is as follows:—

	FEET PER MILE.
1st 16½ miles	54·2
In the next 53 miles to Kelso Bridge, there is not a great difference in the rate of fall, the extremes being from 8 to 11 feet per mile, and the average	9·
In the next 27 miles to Berwick, the mean fall is ...	4·1

It is the uniformity of its fall for so long a course that has conferred upon this river the epithet of the "Placid Tweed." Yet, as it continues to receive gravel nearly to its outfall, it is not a river at all equal in navigable properties to the Tyne, though considerably exceeding the latter in extent of basin.*

The fall of the Thames is remarkably regular. After the first 22 miles from its source, in which it averages 6·1 feet per mile, the rate of fall becomes little more than 2 feet per mile; and throughout a distance of more than 100 miles, to the confluence of the Wey, the declivity is from 18 inches to 2 feet per mile, the average rate being 1·7 feet per mile. The length of its course is 215 miles, and the height of the source 376 feet.

Frisi has the following statement, which is worthy of notice, because it shows the volumes of water as well as inclinations, with a view to the well-known dictum that *the larger the volume of water the less is the slope of the bed. See Fig. 2.*

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* Tweed, 1,870 square miles; Tyne, 1,142.

	VOLUME.	FALL: ENGLISH INCHES TO A MILE.
The Lavino, tributary of Samoggia ...	I.	80⅓ gravel.
The Samoggia, tributary of Reno ...	III.	56 gravel.
Samoggia after junction with Lavino...	IV.	39 gravel and sand.
The Reno alone	X.	27½ sand.
The Reno after its junction with Samoggia	XIV.	18½ sand.
The Reno further down	XIV.	15½ sand.
The Reno ditto	XIV.	13½ sand.

Thus not only do the falls diminish as the volumes increase, but there is in this example a sensible relation in figures between the volumes and rates of fall. Thus the Reno has a volume of 10, a slope of 27½; but after confluence with the Samoggia a volume of 14, and a slope of 18½. Now,

As 14 : 10 : : 27·5 : 19·6 instead of 18½, an approximation of a not distant kind.

But it must be observed that the case of united waters is not the only one in which the slope becomes less; on the contrary, the same current, as it advances on its course, gradually lessens its declivity. For this, Frisi gives the very inadequate reason that the sand becomes finer. In point of fact, as rivers shorten their distances to the outfall, the resistance becomes less in proportion to the remaining extent of friction bed; and, by reason of the abatement of resistance, a greater balance of power goes to excavate, or (which is the same thing) to flatten the bed, even if no accession of volume has taken place.

The fall of the Ganges, according to Rennell, is not more than four inches to a mile for the last 1350 miles of its course, including 300 miles of passage over the Delta.

The fall of the Nile, from Assouan to its outfall, is between seven and eight inches per mile, calculating from the data of Linant.

The fall of the Po near its outfall is about seven inches per mile, and, further up the river, eight or nine inches per mile, where the bed is sand. It would seem that there is not a great difference in the declination of the last reaches of rivers, provided they do not carry gravel into those reaches. The motion of rivers towards the outfall is, in fact, *governed more by the slope of the surface than by that of the bed:* and thus we perceive the justness of the rule laid down by the Italian engineers:—" The greater the volume of water the less is the slope of the bed;" but also, " The greater the volume of water, the greater is the slope of the surface."

In the interior of countries rivers are deepening their valleys by a very slow process, for so long as materials of the same size are to be drifted, the fall will continue the same. When lesser materials are brought in, then the bed flattens in proportion. But while the hills yielding the supply of gravel are nigh, the gravel will maintain its size; when these hills are at a greater distance it becomes proportionably reduced by travelling, as already shown. The rate of deepening river beds in mountainous districts, is therefore commensurate with that exceedingly slow process by which the hills recede from the river bed under the operation of those natural causes by which they are wasted away. And thus a limit appears to be fixed to our views of rendering rivers navigable in the upper parts of their courses; for if we take the fall of North Tyne, for instance, at 13 feet per mile, we shall have, for a dozen miles of its course, an elevation of 156 feet above the horizontal line: but assuming a fall of 30 inches per mile to be as much as the purposes of navigation will admit, then the elevation of bed in the distance mentioned ought not to be more than 30 feet, instead of 156, being a difference of 126 feet, which the upper part of the bed has yet to be excavated in order to render it navigable. In such a case a canal system of navigation, with locks, is clearly pointed out by Nature.

Before confluence, though not absolutely close to it, the falls of two stream beds are greater than they are higher up. This apparent anomaly is explained on the ground that the streams have to fall there to a lower level, that is, into a flatter bed, than either was capable of forming separately, but which their joint volume enables them to excavate. When the streams are of very unequal magnitude, the tributary has suddenly to descend into a bottom deeper than its own, in proportion to the greater power that has been employed in excavating it. It is thus that in a rocky country tributaries join the main river by leaping over cascades, which are not always close to the river, but often at some small distance, the intervening space shewing the extent of work the smaller current has been able to effect, with the aid of its waterfall, in competing with its more powerful neighbour. No better examples of this kind of junction need be sought after than those of western Coquetdale, where the Usway, Barrowburn, and numerous other streams, fall over rocky shelves—taking, as it were, a leap downwards, to join the Coquet.

It will be observed, that the volume of water contained in rivers is often mentioned as a paramount consideration in connection with their beds. Yet, though the volumes of different rivers are very variable, we must, nevertheless, divest ourselves of the notion that there are any such things in Nature as *feeble streams, when their action is regarded as the aggregate of a number of very unequal conditions.* For example, the torrent, which is the most violent of all, is, as a part of its character, dry in summer; the brook, which at times contains hardly enough water to make a sparkle in the sunshine, becomes after heavy rains, turbid, powerful, and

Fig 3.

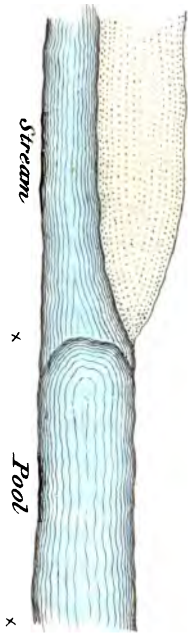


Fig 4.

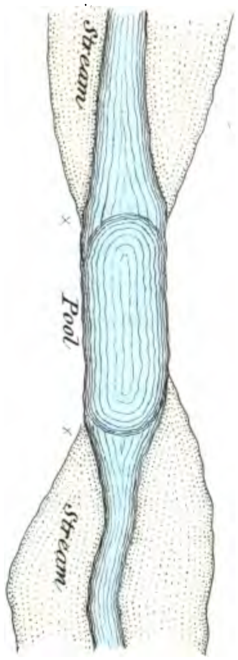


Fig 5.

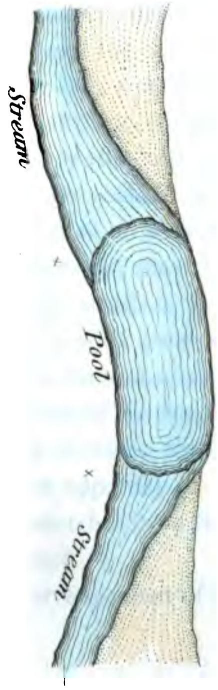
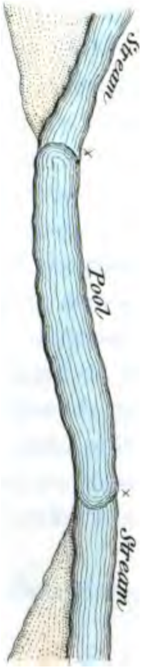


Fig 6.



NOTE.—The Blue Shade shews the Ordinary Bed; and the Brown and Blue together shew the Flood Bed.—In the Pools the Bed is of the same Width in the Flood and ordinary conditions.

dangerous: the river, clear and gentle in one season, at another overflows its banks, and carries with an irresistible current those ruins of the land which are destined to fill up existing lake hollows, or to alter the geographical character of a country by extending its coast line miles and leagues out to sea.

On comparing these various conditions, it becomes evident that *the flood or high water state is the really governing state of rivers.* We cannot, indeed, appreciate the effects produced by rivers from their average condition, and still less from their lowest state; neither can we comprehend the established relation between them and their beds, except by referring it to the flood state. If, for example, the bed of a gravelly river be examined when the water is low, there will be observed a succession of streams and of pools: in the streams the water moves with considerable velocity; in the pools it is almost still. Why then are not the pools filled up? How are we to reconcile the principle of great velocity and an encumbered bed, with that of a slow velocity and the contrary? On further examination we find that the bed, wet and dry together, of the stream, is much wider than that of the pool; and the consequence is, that when the waters are in a state of flood, the conditions of the velocity are exactly reversed: where the stream is, the current has then a wide bed, and where the pool is situated, a much narrower one: in other words, the section of the pool is then the smallest, and the flood current, therefore, moves through it with greater velocity than it does over a stream bed; the mutual relations being thus entirely changed on a comparison of the flood with the ordinary state. There is no difficulty in fixing the distinction between the two beds, as it is at once apparent to the eye. *Figures* 3, 4, 5, 6, are illustrative sketches from Nature, which at once explain what has been stated.

The arrangement of bed under consideration implies a peculiar, and by no means regular, line of section, in gravelly rivers, as illustrated in *figures* 7, 8.*

At *a*, *Fig.* 7, is the head of a stream, which, moving, (on the principle of falling bodies,) with an accelerated velocity as it descends the slope, acquires at *b* the power to excavate its bed, and to form a pool *c*; but this process of pool formation is destructive of its own power, just as the force of a water-fall is destroyed by falling into the pool at its base: the bed *c d*, with a counterfall, is therefore established to *d*, where the nearly level line of the pool surface again approaches the upper edge of the bank: a similar process then commences with the next following stream and pool. The bank, it will be observed, is highest at *c*, being the point where the stream has cut deepest; but the counterfall *c d* acts as an obstacle to its direct course, and being no longer capable of overcoming the resistance of the bottom, it acts laterally on the banks, which become consequently further and further apart as we approach *d*, the current becoming feebler all the while in proportion to the widening of the bed, until at *d* the motion has nearly ceased. We can thus determine the ground plan as well as the section of this figure. *See Fig.* 8, the letters on the plan mark corresponding points on the section.

The current being unable to work directly on its bed, as above shewn, this circumstance has the effect of diverting it in a lateral direction; and, if its banks are capable of being operated upon, it removes a portion of them, and thus widens its bed. This is precisely what happens between the points *c* and *d*. The counterfall prevents the current from maintaining the depth of bed which it possesses at *c*; it begins, therefore, to increase its section in the remaining direction, that of breadth; but with the increase of breadth the velocity

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* *Fig.* 7, and similar figures throughout, are drawn to distorted scales, for the purpose of shewing the vertical dimensions with greater distinctness.

Fig. 7.

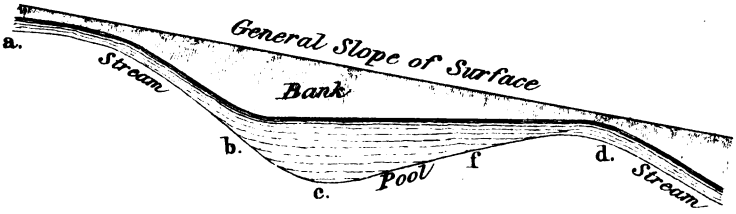


Fig. 8.

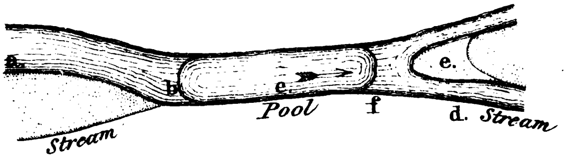
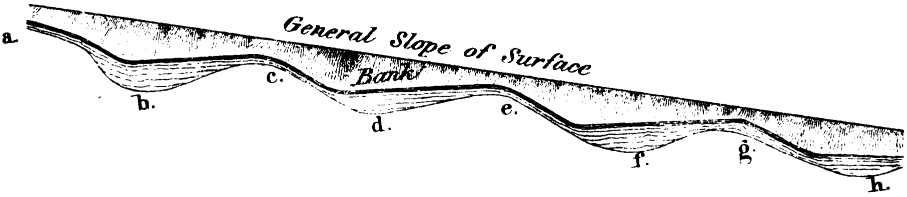
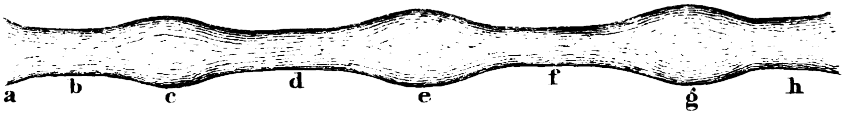


Fig. 9.



SECTION.

Fig. 10.



PLAN.

diminishes: the materials carried past *b* are dropped in *f*; a gravel bed is formed here, which protrudes under water, like a tongue, towards *b*, and the current escapes laterally, either on both sides of the gravel bed *e*; or if one side happen to be connected with the bank, then the current escapes down the side which remains open. Examples of both modes of issue constantly occur; and even the same example varies one sea son from another; for a gravelly river bed, owing to its powerful currents, frequently changes its position.

If then we are to represent a continuous section of the course of a gravelly river, it will be like that of *Fig*. 9. It is obvious, that through this undulating tract certain lines may be drawn conforming to the general slope of bed; a line joining the heads of the respective streams would be one of this description; and it is thus that we discover the real progress of a regular action, notwithstanding the appearance of one which is much the contrary. The entire system of stream and pool is indeed very admirable; its explanation residing in the circumstance that water moves down an inclined plane, upon the principle of falling bodies, with an accelerated, or constantly increasing, velocity. But to this acceleration Nature has set limits, because, if allowed to proceed, it would become quite unmanageable. When, therefore, a certain point of velocity is attained, the current excavates its bed, forms a pool, and by this means destroys its own force. The depth of pools depends manifestly on the rate of fall; and the distance between them is short in proportion to the fall. It is thus that among the rapid declivities of mountain districts, streams work a passage by cataracts with deep holes at their base; further down a stream becomes the substitute for the Linn, and a pool for the Boil at its foot; and gradually as we advance into regions of less fall and finer material, the streams and pools become larger and longer.

As the greatest velocity is at the entrance to a pool, so the least is at the issue from it; and for this reason there are the largest pebbles in the former situation, and the smallest in the latter. This circumstance points out the proper situation for a ford in a gravelly river: it ought to be at the issue from a pool, because there the smaller size of the gravel makes the bottom smoother for a passage.

We must here notice, as the sequel of what has been said, a river principle of the highest importance. Though the actions on the bottom and on the banks are both referrible to an original action on the bottom, yet those actions are to be regarded *as alternate, and not simultaneous ones: for it is manifest, from what has been stated, that the effect of an obstacle which prevents the river from deepening its bed, is to cause a lateral diversion of the current, from which diversion ensues an action on the banks.* This result is no more than may be expressed in the plain matter of fact language, that if the current be obstructed in one direction, it endeavours to find a passage by another; yet we shall afterwards see how important are the practical consequences of the simple doctrine, deducible from the fact of rivers having to descend from a higher to a lower level, that *their primary action is a vertical action, to which other effects on the bed must be referred as their beginning and origin.*

We are thus enabled to perceive that *figures* 9 and 10 represent what may be called the *elementary forms of river beds*, as established by the reciprocal terms of the current's agency on one hand, and the resistance of the bed on the other, and we shall see as we go on, what modifications these primary forms undergo according to the various circumstances to which rivers are subjected.

The irregular height of the banks of gravelly rivers, and the cause of that irregularity, are shown in *fig.* 9. In point of fact it often happens that such rivers have not a fixed bed, and they are proportionally difficult to be controlled. As the bottom becomes more regular in the lower districts, so, by the same induction, do the banks; and a determinate bed is more and more defined as we reach the regions of the finer depositions of the smaller gravels, and, ultimately, of the sands.

I may here entreat the reader to go and examine these things for himself. A few days' actual inspection, with some degree of mathematical knowledge, will give him clearer views than can be gathered from books. It is in the upper courses of rivers, where they flow over gravelly beds, that we find principles broadly exemplified and distinct in their character, just as the mountain tract is bolder in its forms than the plains below it. Further from the source, those principles become blended with each other; are less obvious and more difficult to separate; and have, it may safely be said, led to a great deal of confusion and some error by being studied where their inherent differences are thus shaded away. There are not several sets of doctrines adapted to rivers in different stages of their progress: on the contrary, one and the same doctrine, applied with a due regard to the circumstances, is explanatory of the river with a sandy, as of that with a gravelly, bed.

For similar reasons it is advisable to acquaint ourselves with the principles in question, by means of observations made in those portions of a river which are removed from the influence of the tides. Though the velocity of the tidal wave depends upon the condition of its receptacle, and that condition again is, quoad rivers, dependent chiefly upon the scouring agency of running water, so that we ultimately arrive at the same process of investigation, for tidal, as for simple currents; yet there are in the former, compound elements, owing to the reverse action of the ebb and flood currents, and to other circumstances hereafter explained, which render it preferable to study the subject at first in its simplest form and situation.

We have seen that it is the flood state of rivers which is their really governing state. Their ordinary condition, at the summer level, is one of repose, quite inadequate to explain the actual appearances of bed and banks. A more powerful agent has manifestly been at work, to whose superior energy those appearances are due. It is the flood bed, and not the ordinary bed, of rivers, that we everywhere contemplate.

On similar grounds, the action of a river cannot be appreciated, by considering the rate of its discharge as an average, day after day; on the contrary, the daily volume thus calculated may be capable of doing either a very trifling amount of work, or none at all, unless it surpass the power required to disturb equilibrium. And, in point of fact, the floods and freshes which operate on the beds of rivers are, in our climate, usually confined to a particular season, the action during the rest of the year being almost, or entirely dormant. By viewing the subject in this light, we *can easily understand how a few large floods in a twelvemonth* may constitute themselves the law-givers, as it were, of a river; and we may also appreciate the fallacy of those calculations, so often made, which profess to determine the energy of rivers from the average quantity of their waters: as if it were admissible to strike an average between an operation in which all the work is done, and another in which none at all is effected.

CHAP. III.

Examples of the Power of Running Water—Fall of Rain—Extent of River Basins—General Character of Northumberland Rivers—Floods —Rivers of Australia—Rivers of America.

THE reader has been cautioned that there is not in Nature any such thing as a feeble stream. It will be recollected, that *an inch of rain is equal to a fall of almost exactly* 100 *tons of water on every acre;* wherefore brooks, regarded as insignificant, and which collect the water of only a few square miles of basin, may yet, during heavy rains, discharge very considerable volumes of water, and are then possessed of corresponding, and indeed, surprising power. I have at this moment in view a brook which, in droughty weather, does not carry more than 500 gallons per minute: it has an average fall of thirty feet to the mile, and a run of six miles. In a flood state I have known this stream convey 22,500 gallons per minute, and it has higher floods than the one I happened to measure. However, let us calculate its power at the rate of discharge mentioned, which was ascertained more towards the head than the outfall of the stream, so that the rate of discharge may be considered as below the average for the whole length of course.

The total fall is 180 feet; the quantity is 22,500 gallons, equal to 225,000lbs. per minute; the co-efficient for a horse-power is 33,000lbs. Whence

$$\frac{180 \times 225{,}000}{33{,}000} = 1{,}227 \text{ horses' power.}$$

The whole of this large force is absorbed by the resistance of the bed, excepting only that small remainder which gives motion to the current; but it is not the less on this account a living and actual power in operation, doing its full work as an aggregate. We may conceive the entire force as distributed over the bed, every 100 yards of course absorbing nearly 12 horse power, and every 8½ yards employing 1 horse power; and thus Nature breaks her large forces into smaller ones, which do her bidding gently.

We may take an example of this kind from the Tyne itself. It is not unusual for this river, during a land flood, to discharge 36 millions of tons of water in 24 hours, being equivalent to a *net* quantity of half an inch of rain over the entire extent of its basin. The highest sources are about 1,200 feet above the sea level; but the mean elevation of the basin may be taken at 500 feet. Now 36 million tons in 24 hours are 25,000 tons per minute; and a horse-power being 33,000lbs., equal to 14·7 tons, we have

$$\frac{25{,}000 \times 500}{14{\cdot}7} = 850{,}340 \text{ horses' power.}$$

A flood which rose, at its highest elevation, a few inches above the floor of the house at Ryton island, discharged, according to my calculation, upwards of 70 millions of tons of water in 24 hours (70,383,909), to which may be added the waters at the same time extending over the Haughs, estimated at 9,874,286: in all 80,258,195 tons, or say 80 millions of tons in 24 hours.

By way of contrast, I may mention the quantity of water pasing the same point on July 19, 1850, when the river was free from tide or fresh, and extremely low: the rate of discharge was only 16,025 cubic feet per minute, equal to 659,890 tons in 24 hours.

Thus the Tyne varies in its volume of land water in the proportion of 1 to 120.

The ordinary state of the Nile is to its flood state as 1 to 5.

The ordinary state of the Ganges is to its flood state as 1 to 5.

The gross power of the fall of Niagara is, according to Blackwell's observations, equal to that of nearly seven millions of horses: others, from different data, make it as high as ten or twelve millions, and even more. In fact, taking into account the constancy of its operation, the effort of this great cataract will bear a comparison with that of the entire adult labouring population on the face of the globe.

If, instead of cutting its way at once, *per Saltum*, through the great limestone platform above Lake Ontario, the St. Lawrence had reached the latter by a gradual fall from Lake Erie, the same amount of power would have been in operation as there is now, assuming the levels to be alike. But that power would not then have had the opportunity of manifesting itself, as at Niagara, by a free fall where it encounters no opposition, excepting from the atmosphere through which it cleaves its way: on the contrary, the resistance of the bed, being then in constant operation, and not suspended at any particular point, would have absorbed or employed, step by step, the power of the current.

The magnitude of a river obviously depends, other circumstances being alike, upon the extent of its supplying surface, or basin. We cannot arrive at any other conclusion than this: for as rains and snows are the sources of river water, so it must be held that the quantity of rain and snow which falls upon a given surface, is proportional, *cæteris paribus*, to the extent of that surface. Springs, which furnish the ordinary volumes of rivers, are in the same category, being dependent upon day water for the continuance of their supply. But, in determining the absolute volume of water, these principles must be taken along with the distinctive influences arising out of latitude, mountain ranges covered or otherwise with perpetual snow, and the other causes, remote or proximate, which affect the climate of a country, especially in relation to the quantity of rain. Within the limits of our two northern English counties, which divide the North Sea from the Irish

Channel, there is a very remarkable diversity in this respect; and perhaps no example can more effectually shew the uncertainty of generalizations on the subject. The quantity of rain which fell in various places in this district in 12 months, from June, 1844, to June, 1845, was as follows:—

	Inches,
Harroby, near Carlisle	26
Whitehaven	40
Keswick	44½
Buttermere	66
Emersdale	58
Wasdale Head	84
West Denton, near Newcastle	37
Tynemouth	19½
Average of Tynemouth for seven years	21·8
Average yearly number of wet days at Tynemouth	167

In 1848, which was a wetter year than the one quoted, the differences were still greater; the quantity at Wasdale Head being 115 inches, and at Seathwaite, in Borrodale, it attained the extraordinary aggregate of 161 inches, according to Mr. Miller's observations.

It is thus: that of the district under consideration, which is not more than 75 miles in direct width, one extremity may be regarded as the wettest spot in Great Britain, while at the other the annual fall of rain is a good deal below the average of the island.* The hills of Cumberland and Westmorland protect us, in a great measure, from the Atlantic exposure which causes so much moisture to be precipitated upon themselves: yet a great deal of rain falls with westerly and south-westerly winds on the western watershed of the Tyne from Crossfell to the Keilder Hills, and those rains, of Atlantic origin, frequently swell the river considerably when no rain falls in the lower district. I mention the Keilder Hills as the northern limit of this Atlantic influence, because less rain falls in the basin of the Reid than in that of the North Tyne.

* 31·3 inches.

However, for the last thirty miles of the course of the Tyne and its affluents, there is seldom much fall of rain from the south-west: the very heaviest floods of the Tyne have, therefore, been accompanied by north-east winds. Such was the case with the great flood of 1771, which carried away the old Bridge of Newcastle: and also with many other high floods of the Tyne. The bleak Scandinavian wind occasions in Northumberland, *in a given time*, a more general and abundant precipitation of moisture than any other; not because it is of its own nature, a wet wind; in fact, it is too cold to be so, and often pines out to very dry weather; but owing to its low temperature, it condenses the vapour contained in our milder atmosphere down to the relatively low degree of its own powers of solution.

But if we knew determinately the average quantity of rain which falls within the basin of the Tyne, there would remain to be ascertained the quantity lost by evaporation and absorption—a problem, the elements for the solution of which are not yet provided; though after making a due allowance for these operations, it would probably be found that not more than a third or two-fifths of the entire quantity of rain finds its way down the river courses of a country.* However

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* The following are the means of eight years' observations from 1836 to 1843 inclusive, by Mr. John Dickinson, Hertfordshire.

MEAN OF EACH MONTH, AND OF EIGHT YEARS.

	RAIN. INCHES.	FILTRATION. INCHES.	EVAPORATION. INCHES.	FILTRATION. PER CENT.	EVAPORATION. PER CENT.
January	1·847	1·307	0 540	70·7	29·3
February... ...	1·971	1·547	0·424	78·4	21·6
March	1·617	1·077	0·540	66·6	33·4
April	1·456	0·306	1·150	21·0	79·0
May	1·856	0·108	1·748	5·8	94·2
June	2·213	0·039	2·174	1·7	98·3
July	2·287	0·042	2·245	1·8	98·2
August	2·427	0·036	2·391	1·4	98·6
September ...	2·639	0·369	2·270	13·9	86·1
October	2·823	1·400	1·423	49·5	50·5
November ...	3·837	3·258	0·579	84·9	15·1
December ...	1·641	1·805	0·164	100·0	0·0
	26·614	11·294	15·320	42·4	57·6

Among other facts deducible from the foregoing table, it is observable curious and interesting such an enquiry may be, it does not directly concern our actual investigations; since a land flood is, for us, less a state to be accounted for, than a physical fact, the consequences of which are to be determined: it is, in other words, to be viewed as a result, after the circumstances of evaporation and absorption have been adjusted by Nature herself.

We must content ourselves at present, then, with the general fact, that the volume of water discharged by rivers, is, *cæteris paribus*, proportionate to the extent of their several basins; and we may proceed to state, that the following is an admeasurement of the basin of the Tyne; in other words, of the extent of country, drained by that river and its tributaries.

	SQUARE MILES.
In the County of Northumberland, the extent of basin is	894
In the County of Durham	177
In Cumberland	64
In Scotland, three streamlets, from half a mile to a mile and half in length each before crossing the border, say	7
Total	1142

Length of course, 80 miles.

Distributed as follows:—

	SQUARE MILES.	
North Tyne and Reidwater	473	
South Tyne	267	
Lower Tyne	402	1142

I shall here add the basins of our other Northumberland rivers.

	SQUARE MILES.	LENGTH OF COURSE. MILES.
The Blyth	136	22
The Wansbeck	128	23
The Coquet	232	44
The Aln	86	21

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that the evaporation during the winter months is very inconsiderable, so that in the wettest season nearly all the rain water does really find its way into the rivers.

Owing to the proximity of the summit levels of Northumberland to the sea, our largest streams have rather the character of fragments of the upper courses of rivers, than of those true rivers, which are established over the surface of more extensive countries. Our rivers have too short a run to attain the latter stage; they are less regulated in the mutual action of bed and current, and more liable on this account to mischievous fluctuations; presenting the aspect of streams which have not left the declivities of the country, rather than of those more perfect rivers that wind through extended plains lying at the base of those declivities. This is a peculiarity which must not be overlooked, and which furnishes additional reasons for attempting to supply, by artificial means, what Nature has thought proper to withhold. It is only to rivers like the Thames that Derham's famous lines are applicable:—

> "Though deep yet smooth, though gentle yet not dull,
> Strong without rage, without o'erflowing full."

A better description by the way, of a river in train than has been given by all the hydrographers.

Had the course of the Tyne much exceeded its actual length, it is probable that Art might have been in a great measure superseded; and such an early condition becomes a legitimate object of speculation, when we reflect upon the ravages made by the sea on the eastern coast of England. It is even possible that many of the rivers traversing the Northern Coal Field have at one period coalesced in a more extended basin, and reached the sea by a single outfall.

It is obvious from the foregoing considerations, that the quantity of water in a river constantly diminishes in approaching its source; for the nearer the source the less is the remaining surface of supply; and *é contra,* the further from the source, the greater the surface and corresponding volume. Further, the volume is clearly not a direct proportion of the length of course, but a question of area, that is, of length multiplied by breadth; since we have a right to assume that the width of basin is proportional to its length. Wherefore, of two rivers in similar circumstances, if one has twice the length of the other, it has four times the extent of basin, and consequently four times the volume. The comparative volumes are thus as the squares of the lengths, and not as the lengths simply.

The nearer the source the more rapid is the rise of a flood, because the waters, on account of the shortness of the run, and the declivities of the country, collect very rapidly: but for the same reason they pass away rapidly, whence the nearer the source the shorter is the duration of floods. We may make this comparison as between two rivers, one whose basin is almost a plane, and the other with a basin whose declivities are considerable. In the first-named there are no such violent swellings as in the last. The Thames cannot, for the reasons assigned, have such rapid floods as the Tyne: rivers of long courses and in regular train, possess an equalising power over their floods, the waters of which reach and leave them very gradually, so that the same operation which is completed in 24 hours by one, may extend over several days in the other, and is proportionably less active as it is more prolonged and diffused.

A river may be constantly in a state of flood, provided that it always rains in some part of its course, and that each following rain occurs soon enough to send down its waters before those of the former flood have passed away. This condition cannot, however, obtain, except in a river of vast extent, intersecting various climates in its course, whose rains act upon it at distinct and regular periods. The Mississippi and its confluents, which flow from 50° to 29° 20′ N. L., and have a basin nineteen times the area of England and Wales, approximate to this state.

To produce the *largest* floods, it is necessary that the fall of rain be general throughout the course of the river: that the rain lasts long enough to enable the flood waters towards the source to join those towards the outfall; and that the duration of the rain be great in proportion to the length of the river's course, for the longer such course is, the longer is the time required for the water in the upper districts to travel to those below. These conditions are seldom concomitant in rivers with long courses, and it therefore happens that in such rivers extraordinary floods occur but seldom, while the conditions are realized in small brooks and torrents, as may be exemplified everywhere, in the channels of the streets, or the remote gullies of the hills, where, on the occurrence of a "thunder spit," the dry water-courses are suddenly filled with furious torrents. All this may be regarded as secondary to the profound plans of Nature; the great river has already done its work, and is left in comparative repose, but the torrent has much to do, and is to be provided with means accordingly.

It follows from what has been said, that long-continued general rains are more calculated to occasion large floods in rivers, than short rains, though the latter may yield locally a larger quantity of water. Often, after a thunder-storm, the water of a river, though without apparent fresh, will be found more turbid than during floods: in this case the rain has fallen for a time very heavily, and washed a great quantity of mud and silt into the river, but did not last long enough, and was too local, to alter at all materially the volume of water. Two conditions met therefore on the same side, an ordinary state of the water, and an excess of silt: whence the extraordinary state of pollution.

When a country is covered with snow, and a general thaw ensues, great floods are occasioned, because the melting of the snow is equivalent to a general rain throughout the river's course.

Cultivation will diminish the ordinary volume of water in rivers, because furrows and drains are operations for facilitating the passage of water to its lowest level; and it is owing to the want of such means of escape that when the moors are soaked by rains, the water stagnates and lodges there, being retained as by a sponge. Whence arises the coldness of these hill tracts in early summer; for much of the water in question has to be evaporated at the expense of the heat which would otherwise warm the ground. The mosses from which the upper feeders of rivers are often derived, give out their contained water slowly; but as a first step in cultivation, such land must be drained: neither is it again saturated by rains, for the waters are carried away as they fall, instead of being retained to yield a future supply. Rock springs will also be affected; their sources, less copious in summer than in winter, will no longer be replenished as they are now, if the day water of the wet season be directed to the lowest levels as fast as it falls. The same train of causes which will thus diminish the ordinary volume of rivers, will increase their flood volume, by reason of the greater facility with which the rain or snow waters leave the land. And the more rapid the flood, the greater is the quantity of debris. Besides, a wild country is generally protected by some kind of vegetation, as heath, wood, moss, or grass : while a cultivated district is brought by the plough into a condition in which its materials are easily removed.

In the remaining portion of this chapter we may notice some special cases of rivers, which appear to vary, in certain features, from the general character.

The inundations of the Nile are owing to tropical rains beyond the limits of Egypt, which has scarcely any rain.* The lower part of the basin of this river is very narrow, being hemmed in by the desert on each side, so that for the last 1,200 miles of its course it receives no tributary, a re-

*1·338 inches yearly, on the average of 5 years at Cairo. One fall of hail during the five years : no frost or snow : annual mean temperature 22·4° Cent., equal to 72⅓° Fahr. (Clôt-Bey.)

markable, and, so far as known, a unique circumstance in the history of rivers, to which is probably owing the soft and palatable quality of its waters; for no new saline or vegetable matters are brought into its stream, while those it already contains have time to separate in so long a solitary course. For the same reason, the river does not enlarge its volume in approaching the sea: on the contrary more water runs past Khartoom, at the junction of the Blue and White Niles, than flows into the Mediterranean; for not only is no addition made to the volume, but a considerable abstraction takes place by evaporation, irrigation, &c.: in fact the great valley is cracking with drought when the first floods arrive in June.

The Nile, therefore, discharges less water than many rivers of an equal, or even inferior extent, of basin. The Ganges and Burrampooter together have not so large a basin as the Nile: but with the south-west monsoon heavy rains fall throughout the whole length of their course, and they discharge more than double the ordinary, as well as flood volume, of the Nile.

The rivers of Australia present great anomalies. There are not in that continent any first-class rivers; and such as there are, differ greatly from those of Europe in the upper part of their courses. Relatively with other countries situated near and within the Tropics, there appears to be a great deficiency of aggregate rain in Australia, yet in falling, it falls for the time with something like tropical violence: owing to these combined circumstances the waters, instead of being stored for perennial supply, pass off at once through large gullies, which are of too great a magnitude to be regarded as the beds of torrents, and yet are not legitimately entitled to be called rivers, owing to the absence of that essential quality of rivers—a constant supply of water. This is a great, and probably a fatal drawback to the prosperity of the central tracts of a country where Mitchell had so often occasion to register the Thermometer in his tent at upwards of 100° Fahrenheit.

These gullies are, as already mentioned, often of great magnitude. One, on the river Victoria, is described as a deep section of 400 yards. Some are lost in the neighbouring territory: others terminate in a marsh, and a third-class unites with the more continuous water courses of the country. The water in them is ponded, or collected in pools, without any run between them, upon the pool principle, as before described, and which here answers a very providential end, since without it there would not be any water during the dry heats, in the tracts of country described.

Great floods sometimes rush down those gullies: the author describes one he himself witnessed in the Macquarrie, a tributary of the Darling. It was much longer in arriving than they expected from the report of two policemen, who had been in its company twenty miles the day before, and had then ridden away from it: two of his own people were also nearly caught by it up the river, and he then stationed a man with a gun to give warning of its approach, but night came on, and the man returned. All this was very tantalizing to men situated as his party were, beating about the country, and "impeded in their journey solely by the almost total want of water; suffering excessively from heat and extreme thirst." At length the flood came by moonlight: "The rushing sound of waters and the loud cracking of timber announced that the flood was in the next bend. It rushed into our sight, glittering in the moonbeams, tossing before it ancient trees, and snapping them against its banks. It was preceded by a point of meandering water, picking its way, like a thing of life, through the deepest parts of the dark, dry, shady bed, of what thus again became a flowing river."

It must be added, that the point where this cataclysm was observed, is upwards of 250 miles in a direct line from the source of the Macquarrie, being a distance of about 100 miles, more than the entire direct length of the Thames. Here then is an instance of a stream which retains, at 250 miles from its sources, the essential character of a Torrent, that of being dry at one time, and in violent action at another. But what can be made of a country in which people, finding no water, are obliged to wait, like Mitchell and his party, until it reaches them by means of an accidental fall of rain among the hills?

The great features of the American Continent are most conspicuous in its rivers. The Old-World has equal or loftier mountains; the Caspian is more extensive than any of its inland lakes; and its plains are rivalled by the Steppes of Russia and Tartary; but in its rivers it is unequalled. The Maragnon flows through a wilderness of more than 3,000 miles, resting on the Andes at one extremity, and on the Atlantic at the other; great in all its features, and destined perhaps to be one day, the most productive portion of the globe. Yet that immense region, the basin of whose rivers occupies more than twenty-nine times the area of England and Wales, is now scarcely inhabited by civilized man.

CHAP. IV.

Resistance—Absorbs much the greatest Proportion of the Power of Running Water—Varies with Volume—Terms of—Examples—Velocities required to transport Materials—Relative Velocities at Surface and Bottom— Illustrations—-Glacis-like Form of River Sections—Flood Heights of Rivers—River Beds must be adapted to convey very variable Volumes of Water—Experiments.

Guglielmani shews, in a very simple way, the effects resulting from the confluence of two rivers. "You are to consider," says he, "that after union, there are only two banks instead of four: less frictional surface is therefore exposed, and a consequent increase of velocity ensues. But this increase of velocity causes the current to excavate its bed, which therefore becomes deeper; and, with its augmentation in depth, the other dimension of the cross section, that of breadth, becomes less: whence the well-known fact that one river receives another without a corresponding increase in breadth. In cases where the receiving river is large and established there may, in fact, be no perceptible increase of breadth."

The variable nature of the resistance of rivers, here so plainly pointed out by Guglielmani was, however, lost sight of by Pitôt, who supposed that in running waters, as in hard bodies, the same quantity of motion is always preserved; and, from this hypothesis, concluded that the common velocity of the united rivers is equal to the quantities of motion in the two separate rivers, divided by the sum of their quantities of water, a doctrine which is entirely contrary to experience. Pitôt's mistake consisted in his not dealing with the real momenta of rivers: what he called such are only the apparent ones, being the forces which remain after the

Fig. 11.

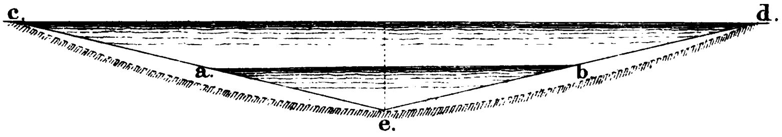


Fig. 12.

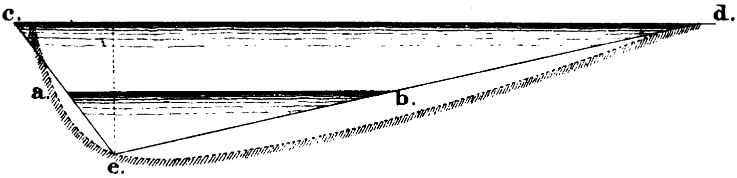


Fig. 13.

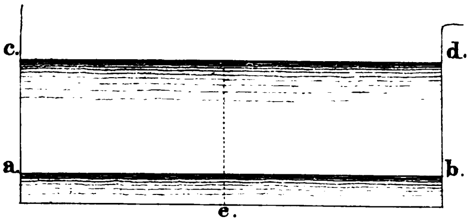
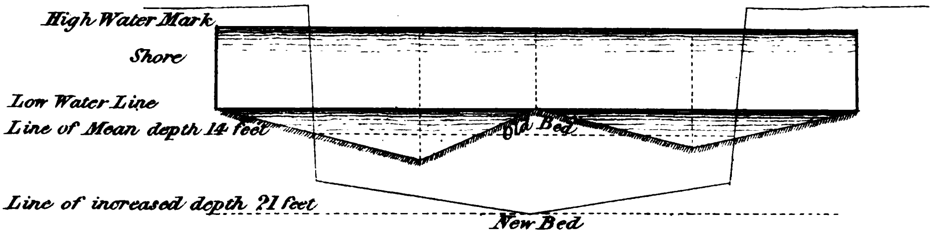


Fig. 14.



greatest portion has been absorbed in overcoming the resistance. The true momentum of a river is its volume multiplied by the function of velocity deduced from the mean height of its basin above the sea: and when the momenta of rivers are spoken of, the distinction here noticed should be borne in mind.

Having mentioned the variable resistance of rivers, it may be advisable here to give an example or two of the manner in which resistance is affected by volume, more especially as the opportunity may be taken of explaining such principles of the motion of fluids as we must be familiar with in order to understand the subject. For this purpose I shall take the case of sections of the same river in the respective states of low water and of flood.

In the three figures, 11, 12, and 13, the two first are common forms of river sections; the third is not so, except when constructed artificially: in a bed of rock a section approximating to this degree of regularity may, however, be sometimes seen. In all the figures the low water and high water sections are supposed to be respectively alike, namely, 200 square feet at low water, and quadruple that area, 800 square feet, during a flood. In Nature the differences are much greater: the Tyne, for instance, rises sometimes 15, and in very rare cases 20 feet, above the summer level at Newburn, where the mean depth of its low waters is not more than three feet. In actual experience there occur, therefore, differences of much greater magnitude than are here exhibited in illustration of a principle.

The few premises required to be attended to are as follows:—

1. The resistance encountered by a current, is as the surface exposed to its action, that is, as the wetted surface multiplied by the length of channel.

2. The resistance must be assumed to be divided amongst all the particles of fluid contained in a cross section, and as

the number of particles so contained is proportional to the area of the section, the effective resistance is, therefore, so much the less as that area is larger, and *vicé versâ.*

The truth of the foregoing principles is very obvious; and the third becomes equally clear, on a little consideration.

3. The force with which an object is struck by a fluid is as the volume of fluid multiplied by its velocity; just as in the case of solid bodies, striking against each other: but there is this peculiarity in the nature of fluids, that a double velocity implies also a double volume; in a solid, this may not be the case, because the *same* solid may strike an object with double the velocity it had before, and the force of the blow is then no more than doubled. But a double velocity of fluid is necessarily, in the same section or surface struck, accompanied by a double quantity of fluid, wherefore the double velocity acts with a force not merely twice, but *four times* as great as before. This is what is meant when it is stated that the impulse of a fluid is as the square of the velocity: and since friction must be regarded in the same light as that of a force conveying sensible impressions, on the ground that action and reaction are equal, so it follows that the friction of a fluid is as the square of its velocity.[*]

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[*] $\frac{s\,l\,v^2}{a}$ is therefore a universal expression for the resistance of fluids, where

s is the wetted surface,
l the length of channel,
v the velocity,
a the area of the cross section.

If we put h for a motive power or water pressure and change the terms, then v^2 is proportional to $\frac{h\,a}{l\,s}$, or which is the same thing $v \backsim \sqrt{\frac{h\,a}{l\,s}}$. In the case of a circle or pipe d the diameter is equivalent to $\frac{a}{s}$. Whence $v \backsim \sqrt{\frac{h\,d}{l}}$.

We want then a co-efficient by which to multiply the above expression, and this has already been found in the case of pipes or water boxes with

We may now apply these plain principles to determine the comparative amount of resistance. The element of length of channel is omitted, as being alike in all.

In *Fig.* 11, the low water section is the triangle *a e b*, the area of which is 200; the wetted surface is $a\ e+e\ b=100{\cdot}3$. Then 100·3 friction bed, divided by 200 area, gives the ratio of the resistance ·5015, a number to be compared, by the same process, with the others. We may compare it first with the friction of its own enlarged current.

Here the area of the triangle *c e d* is 800; the wetted surface $c\ e+e\ d$ is 200·6, and $200{\cdot}6\div800=\cdot2500$, which is just *half the effective resistance of the first.*

In *Fig.* 12, the areas are as before. The wetted surface *a e*, *e b*, is 102.

$$\text{Then } \frac{102}{200}=\cdot5100$$

The area of the larger bed is 800; the wetted surface 204:

$$\text{and } \frac{204}{800}=\cdot2550,$$ being again just *half the effective resistance.*

In the next *Fig.* 13, we shall find a greater difference,

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a fixed bed. For pipes Prony makes it 48·62: Daubuisson 48·13: and Eytelwein 50; but the two latter vary the expression by making the divisor $l+36d$, and $l+50d$ respectively. From experiments of my own on a straight range of pipes, six inches in diameter, and above a mile long, I have deduced 48·07: but when the pipes were not in prime order, and rather furred, 42·9: terms all in English feet, and velocity in English feet per second. I should prefer the last named number, as safest to work with in practice.

EXAMPLE.—With what velocity will water move through a range of 18 inch pipes, five miles long, the level of the reservoir being 150 feet above that of the point of issue?

18 Inches= 1·5 feet
5 Miles =26400 feet

$$43\sqrt{\frac{150\times1{\cdot}5}{26{,}400}}=43\times\sqrt{\cdot0085}=43\times\cdot092=3{\cdot}956 \text{ feet per second velocity.}$$

Quantity: Area of pipe 1·767 sq. foot×3·956=6·99 cubic feet×6·23=43½ gallons per second, equal to 2610 gallons per minute.

The theoretical velocity in this case is $(8\sqrt{150}=)$ 98 feet per second, being nearly 25 times the actual velocity.

because the surface increases very little relatively with the additional quantity.

a b is 200 in area, and 104 in wetted surface.

Then $\frac{104}{200}=\cdot5200$.

a b c d is 800 in area, and 116 in surface.

Then $\frac{116}{800}=\cdot1450$ only, for the effective resistance ; being no more than between a third and a fourth of the *effective resistance at low water.*

For the sake of greater clearness, we may put the results in parts of 100 :—

	EFFECTIVE RESISTANCE.	
	SMALL SECTION.	QUADRUPLE SECTION.
Fig. 11	96½	48
Fig. 12	98	49
Fig. 13	100	28

Such are the results, plainly put in figures, of variable volumes of water in rivers, upon the effective resistance encountered by their currents. The effective resistance being thus reduced in the proportion of 2 or 3 to 1 during even moderate floods, a balance or excess of power accrues, which goes to increase the velocity, so that by a quadruple water section, not merely four times, but much more than that rate of increased quantity, is discharged, and this is what we are now to calculate.

According to the observations under head 3, the squares of the velocities will be inversely as the previous numbers; and consequently the velocities are inversely as the square roots of those numbers. Assuming, then, that the velocity in the least sections is three miles an hour, we have the following proportions and results for the velocities in the larger sections :—

VELOCITY IN SMALL SECTION.	INVERSE PROPORTION OF SQUARE ROOTS OF EFFECTIVE RESISTANCE.	VELOCITY IN LARGE SECTION.
3	6·9 to 9·8 (48) (96½)	4·26
3	7·0 to 9·9 (49) (98)	4·24
3	5·3 to 10· (28) (100)	5·66

Now the small volumes are each 200×3=600, and the quadruple volumes at three miles an hour, are each 2400; but instead of three miles an hour, we have 4·26, 4·24, and 5·66 miles an hour; wherefore the new volumes are 3408, 3392, and 4528; and the real increases of volume are not as 1 to 4, but as 1 to 5·68, 5·65, and 7·55 respectively.

While on this part of the subject, we may put a case to shew the resistance arising out of the artificial contraction of a river, with a view to deepen its bed. *See Fig.* 14, with the details and dimensions marked upon it. The actual section of the bed is a very bad one, shewing that the river is here divided into two currents, with a sand bed between them.

The mean depth at high water is 14 feet.
The breadth is 1,200 feet; the wetted surface 1,224 feet.
The velocity 3 miles an hour.
The contracted breadth is 800 feet; the wetted surface 828 feet.
The mean depth required to give an equal section is, therefore, 21 feet.
When the contraction is *first made*, the velocity requires to be 4½ miles an hour, to compensate for the loss of breadth.

The comparative resistance is, therefore, as follows:—

		IN TERMS OF UNITY
1. The actual section is 1200×14=16,800: and	$\frac{1224 \times 3^2}{16800} = \cdot 66$	1·43
2. The new section *at first* is 800×14=11,200: and	$\frac{828 \times 4{\cdot}5^2}{11,200} = 1{\cdot}49$	3·24
3. The ultimate section is 800×21=16,800: and	$\frac{842 \times 3^2}{16,800} = \cdot 46$	1·00

Thus, we find that in this example, by a contraction of one-third in breadth, the resistance, *in the first place*, increases in the ratio of more than 2¼ to 1; and though it ultimately becomes much less than it was originally, yet in the interval, the effect upon the river is similar to that of "furring" in a pipe. It is, therefore, evident that an accurate judgment cannot be formed of the effect of river contractions, until their work has been accomplished. The first effect may even tend to cause too hasty a condemnation of the whole design, more especially because the increased resistance explained above is not the only mischievous consequence that immediately follows contraction. The augmented velocity of the current in the contracted space occasions a counterfall adjacent to it, upon the pool principle, and a lateral diversion of the stream ensues, with its consequent evils of sand beds in the middle of the river, and probably also more multiplied windings of the current; evils which are only to be removed by carrying the works systematically through.

On the considerations stated, we can explain the interruption to the tidal flow of water experienced in the Tyne since the construction, *at particular points*, of works intended to regulate its bed: while the partial nature of those works precludes a correct judgment being formed of their ultimate effects, as well as of those which would result from a more extended plan of the same nature.

The early engineers discovered some efficacy in the plan we are discussing. "If," they said, "a River with the width *a c* (*Fig.* 15) has a certain quantity of water passing over each of the three divisions *a*, *b*, *c*, then by narrowing it to two of those divisions *e*, *f*, is it not manifest, that one half more water than before will pass over each division; and is not this the same as an increased volume?" I mention this, because, without at present giving any final opinion on the plan of restricting the beds of rivers, I must yet be allowed to say, that the question is not so much one of absolute volume, as it is of the relation between volume and resistance. Were it otherwise, we might despair of the improvement of rivers with limited volumes of water. In many aspects there is not so much difference between first-class and inferior rivers as might be supposed. The Misissippi does not carry heavier detritus than the Tyne: at its outfall it passes over shoals which render it scarcely navigable by ships

Fig. 15.

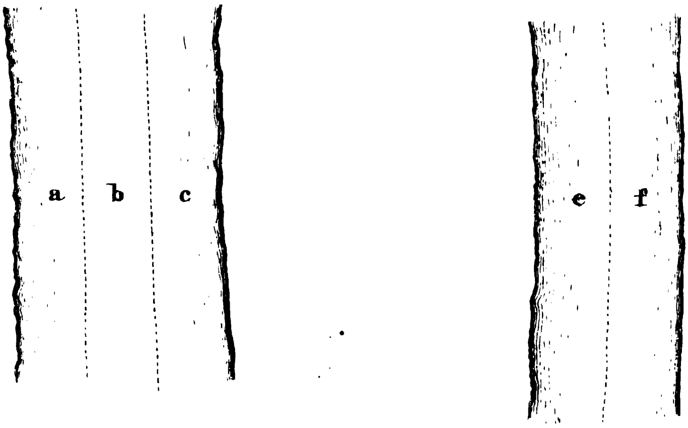


Fig. 16.

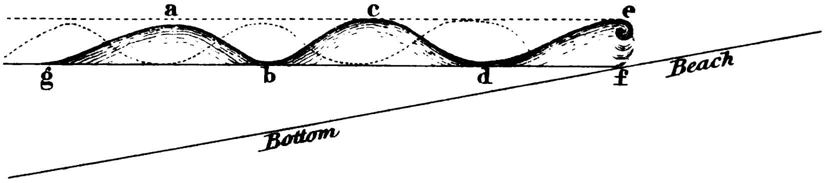
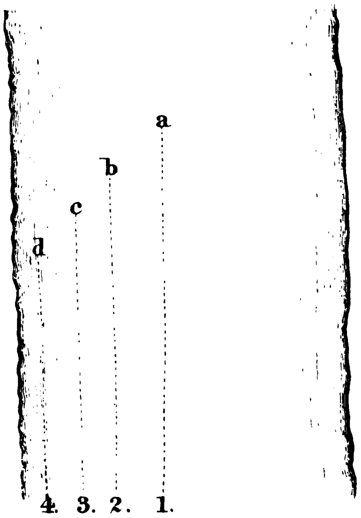


Fig. 17.



of moderate burthen; being, in this respect, much inferior to the Tyne. Yet, if mere volume is to prove so efficacious, that of the larger river is at least 400 times more than that of the smaller. There is, in reality, a uniformity of character in the lower reaches of rivers, because the kind of debris conveyed by them is there very much alike in all; and for the same reason, a practical limit to their velocity resides in the circumstance that materials of a definitive magnitude are carried by their currents. In other words the velocities of rivers are established in correspondence with the yielding nature of their beds; and whatever power they possess beyond this final or terminal velocity must, from the nature of the case be neutralized. Now we shall see immediately that the velocities due to the transporting of even the large gravel of river beds are by no means great, relatively with the theoretical force of the river. The balance of that force is therefore absorbed by other elements of resistance.

It must be confessed that very little dependence is to be placed on any experiments yet made, which profess to determine the velocities required to transport materials of different weight. Du Buat's trials, in this, as in other parts of the subject, were made in wooden boxes, which are so little analogous to the beds of actual rivers, that no secure reliance can be placed upon their results. Besides, it was the fault of the last age to expect too much from pure Mathematics. Our own classifications do not, in all cases, coincide with experience. Small gravel and large are found together, and move together in river beds, as well as apart: and sand, from the *set* it takes on the bottom, may be more or less difficult to put in motion than gravel. Under these variable circumstances, it is not, perhaps, surprising, that one authority states coarse sand to be moveable by a velocity of one foot in a second, while another affirms that two feet per second are required to shift the same material, a difference of not merely double, but of quadruple, the force, bearing in mind that the impulses of fluids are as the squares of their velocities. The following are a few of Du Buat's results :—

	VELOCITY OF CURRENT. INCHES PER SECOND.	SAY MILES PER HOUR.
Coarse yellow sand	8½	½
Gravel the size of a pea, the same, or rather less		
Gravel the size of a bean	13	¾
Gravel the size of a hen's egg	38	2⅙
All the substances	48	2¾

The velocities are those of equilibrium, so that the least excess beyond them will, it is stated, put the corresponding material in motion. Little value is, however, to be attached to these and similar experiments. In river beds materials shelter each other against the action of the current; the smaller ones drop behind the larger, and thus not only save themselves, but prevent the larger ones from moving by the additional resistance thus created. In an experiment made by myself, which has no other merit than that of being tried in a natural bed, the velocity was 31 inches per second at the bottom, as ascertained by a green gooseberry. The bed consisted of pebbles, varying from the size of a sparrow's egg to that of the stones made use of for macadamised roads. On raking the bottom with a stick, all the pebbles got into motion, but on ceasing this disturbance, they again became fixed. The reason is obvious enough: when disturbed, the large and small materials got into motion together: the whole bed then moved, but the smaller materials, which found themselves behind the larger ones, presently dropped, and formed an obstacle to the progress of the others, and thus arises a condition of friction which is most difficult to be measured: for not only the resistance of a body moving over an uneven surface, but also the shifting and unstable nature of that surface itself, are to be taken into account. Add to these considerations the occurrence of sinuosities and counterfalls, and it is easy to perceive that actions of so irregular a character cannot be reduced to determinate and simple rules. We may not say that a velocity of 31 inches per second is sufficient to shift all the gravel equal to, or below, the size of a pigeon's egg: it can only be affirmed, that this rate of velocity will have the effect assigned under the circumstances in which the observation was made.

Having quoted an experiment of my own, I may also mention that I have had occasion to observe sand does not lie in the beds of brooks, where the velocity at the bottom is 12 inches per second; but in this case the sand is again found wherever the widening of the bed occasions a diminution of velocity, and the consequent establishment of a counterfall.

Were it not for the particular *Set* taken by materials in the beds of rivers, it would be difficult to show why large materials are not drifted by water currents as easily as small ones. Let us take, for instance, two similarly formed pieces of gravel, one of which is two inches in a certain lineal dimension, and the other eight inches in the same dimension.

1. The weights of the stones are as the cubes of the same lineal dimension; in other words, as the solidity.

Therefore 2 =8 weight of smaller stone.
8 =512 weight of longer stone.

2. Common stones lose about $\frac{2}{5}$ths of their weight by immersion, a circumstance which most materially assists the transporting power of currents. It is not strictly necessary to introduce this element into the present calculation, because the proportional weight lost is in both cases alike; yet in order to work out all the details, I shall deduct $\frac{2}{5}$ths from the weight of each, leaving for the net weight of the smaller stone 4·8 : and for that of the larger 307·2.

3. The forces acting on the stones are as the surfaces exposed, that is, as the squares of the like lineal dimensions, whence.

$2^2 = 4$ force acting on smaller stone.
$8^2 = 64$ force acting on larger stone.

4. Then

$$\frac{4{\cdot}8}{4} = 1{\cdot}2 \text{ impulse required to move small stone.}$$

$$\frac{307{\cdot}2}{64} = 4{\cdot}8 \text{ impulse required to move large stone.}$$

Thus the impulse required to move the large pebble is only *four times* more than that required for the small one, though the weight of the former is 64 *times* as great. The cause is very obvious: in the material which is heaviest, the surface is also more extended, and receives a proportionally greater aggregate impulse from the current. The general expression is as $\frac{l^3}{l^2}$ to $\frac{l'^3}{l'^2}$, where l, l', are the like lineal dimensions of pebbles similar in form and substance: but $\frac{l^3}{l^2}$ and $\frac{l'^3}{l'^2}$, are equal to l and l' respectively, whence the powers required to move the pebbles are not as the weights, but as the lineal dimensions, as above shewn.

5. Another step might lead to the conclusion that large stones are as easily moved by currents as small ones; for assuming the friction to be, according to a well known law, as $\frac{w}{d}$, where w is the weight, and d the diameter or other like lineal dimension, then in the case given, both results would require to be divided by d, and we should have $\frac{1{\cdot}2}{2} = {\cdot}6$, and $\frac{4{\cdot}8}{8}$ also equal to ·6, making the impulse required for each exactly equal on the same unit of surface.

But stones do not move in river beds like regular bodies upon plains, or coach wheels on Turnpike roads: the largest stones in those beds undergo, as has been said, a kind of burying process, which renders it most difficult to appreciate their actual amount of resistance; and even smaller stones are so mixed up with other materials, that we cannot measure their friction by any ordinary rule. Upon the whole, therefore, we must be content to assume that the resistance of the materials of river beds is practically as their weight. But it should also be remembered, that in particular situations, where large stones are not surrounded by other materials, the resistance may be *much less than the proportions of the weights.* Examples of this kind may be seen where isolated fragments of rock lie on a hard and naked beach; such fragments, though weighing many tons, are yet knocked about by the waves with comparative ease, on the principles explained.

It is doubtless best, in this case, to observe Nature, who accommodates the means to the end. In the upper courses of rivers she employs, to carry their materials, velocities of from five to seven miles an hour: while the lighter materials of the lower courses, are shifted by velocities of two to four miles an hour. And thus we revert to the original proposition, that the powers in exercise to disencumber river beds of their depositions are of very small amount compared with the aggregate powers of rivers, the difference being absorbed by other forms of resistance.

One of the effects of friction is to cause a less velocity at the sides and bottoms of rivers than at the surface and in the middle. In some trials of my own, I found the velocity at the surface to be 22 inches per second, and at the bottom 12 inches; in another experiment 10⅓ inches at surface, and 5¾ inches at bottom; in a third 11 inches and 6 inches respectively. Watt ascertained in a canal 4 feet deep, that the velocity at the surface was 17 inches per second, at the bottom 10 inches, and in the middle 14 inches. I have arranged thirty-one experiments of Dubuat, from 10·91 inches to 48 inches per second of surface velocity,* with the following mean results:—

---

* Old French inches, equal to 11·63 and 51·17 English inches per second respectively; or very nearly, from ⅔ of a mile to 3 miles an hour.

1. Velocity at surface	27·81	Inches.
2. Velocity at the bottom	18·07	„
3. Actual mean velocity	21·54	„
4. Mean velocity calculated at ⅘ths of the velocity of the surface	22·24	„
5. Mean velocity, considered as an arithmetical mean between the surface and bottom velocities	22·92	„

The mean velocity may be taken practically at ⅘ths of the surface velocity, without material error. But when the surface velocity exceeds 5 feet per second (3½ miles an hour), the approximation is closer, as shewn in the following table:—

Velocity at surface ...	4	20	40	60	80	100	120	140	160	Inches.
Ratio of mean velocity to surface velocity...	·76	·78	·81	·83	·85	·86	·87	·88	·89	„

As a mean result, the velocity at the bottom is ⅔ds. that of the surface; or the velocity at the surface is half as much again as that at the bottom; and this relation is nearly uniform for velocities, from 12 to 60 inches per second; but in low velocities, those for example, below a surface rate of a foot per second, the velocity at the surface bears a greater ratio to that of the bottom, the reason of which it may not be difficult to understand; for a certain degree of surface velocity, as suppose 3 inches per second, may be required before any motion can be given to the bottom; and such 3 inches constitute a sensible proportion of velocities under 12 or 15 inches, though not of those of 25, 30, and upwards; and thus we also find that at high velocities, such as 100 or 120 inches per second, the surface and bottom velocities constantly approximate more nearly.

It is not difficult to deduce, from the foregoing experiments, an empirical rule, which will give, in practice, sufficiently close results. For, as the velocity at the bottom increases in a ratio somewhat less than that of the square roots of the surface velocities; so, if we deduct unity from the square root of the surface velocity, the square of the remainder will give the bottom velocity:—

$s = (\sqrt{S} - 1)^2$ where S is the velocity of the surface, and s that of the bottom.

Ex. 1.—With a surface velocity of 36 inches per second, what is the bottom velocity?

$\sqrt{36} = 6$, and $6 - 1 = 5$. Then $5^2 = 25$ inches bottom velocity; the actual velocity was 24·8 inches.

Ex. 2.—Surface velocity 11 inches:—

$\sqrt{11} = 3{\cdot}316$: and $3{\cdot}316 - 1 = 2{\cdot}316$, which squared gives 5·36 inches for the bottom velocity; the actual velocity was nearly 6 inches.*

There is no happier illustration of the effect of difference of resistance in the upper and lower parts of a fluid than the breaking of waves on the sea shore. As the base of the wave gradually approaches shoal water, it becomes more and more retarded, while the crest, at a greater distance from the bottom, maintains a greater velocity, overtakes the lower portion of the wave, and at last breaks, or falls, over the top of it.

When the wave *a*, *Fig.* 16, is in deep water, *a g* and *a b* have the same slope; but at *b* the resistance of the bottom is felt, and the movement is then less rapid along the base of the wave than by the top; wherefore *c d* is steeper than *a b*. Again, the progress of the wave is still slower along *d f*, until *e f* becomes very steep, and the wave tops over, or breaks, at *e*.

We are now to estimate the gross resistance of rivers: and we shall find that not only is that resistance an element of importance, but that it is by far the most material one with which we have to deal.

The very great degree of friction experienced by fluids in motion, even when they occupy regular beds, is shewn in the conveyance of water through pipes. In the note, page 40, an example is given where the actual velocity in pipes 18 inches diameter is only $\frac{1}{23}$ of the theoretical velocity: or, if we consider the column producing motion to be divided into 1000 parts, then the terminal velocity is due to no more than $1\frac{2}{3}$ of those parts, the remaining $998\frac{1}{3}$ parts being absorbed in overcoming the resistance.

---

* Or, if we double the mean velocity, and deduct from the product the surface velocity, the remainder gives the bottom velocity, very nearly.

In prosecuting a train of experiments on the motion of atmospheric air in mining channels, I have found similar results. It is not unusual for mines in this district to be ventilated by a force represented by a vertical column of from 100 to 150 feet of air at 50° Fahrenheit, which we may take at 120 feet as a medium: and the theoretical velocity due to this height is about 88 feet per second; yet the actual velocity does not average more than 4 to 5 feet per second in the mining channels, and the height of column due to this velocity is only $\frac{3}{10}$ths of a foot. It thus appears, that of 1000 parts, not less than 998 are employed in overcoming the resistance, and 2 only are due to the ultimate velocity. In reality the advances made in mine ventilation of late years are mainly owing to modifications of *the resistance, which furnishes, as we may say, so large a reserved fund for improvement.*

Let us next endeavour to draw an illustration from rivers themselves, of the friction and ultimate velocity of fluids.

If we could find a river with uniform materials in its bed for some hundreds of miles, joined by no tributary within that distance, of known volume of water, and ascertained difference of level between two distant and given points of comparison: then most of the data for the solution of the problem in question would be given. To the character of such a river the nearest approximation I know of is furnished by the Nile: and though all the requisite conditions may not be fulfilled in that great stream, yet we shall find it, perhaps, the most suitable for our purpose.

This river has been submitted to the scale and compass of the engineer: it has few causes of disturbance along the lower part of its course, since during the last 1200 miles it possesses the unique property of receiving no tributary. Let us then try to determine the amount of resistance experienced by it from the first Cataract to the sea, a distance of 740 miles, over which it flows on a bed of sand and mud, the result of its own depositions. At the Cataract the bed of the river is 553 French feet, equal to 592 English feet, above the Mediterranean. The velocity of the river at its outfall may be taken at five miles, or say 7·3 feet per second, and the height of column due to this velocity is less than seven inches (·56 foot): therefore, the whole power employed being represented by a column of 592 feet, all is absorbed by the resistance excepting seven inches; that is, out of 1000 parts of force, more than 999 are employed in overcoming resistance, and less than 1 part is due to the ultimate velocity.

The foregoing figures furnish the materials of a theorem which would have at least the merit of being drawn from Nature. Yet, if such a theorem be deduced, it must be with a protest that it is applicable to the particular case: and that, if its use be extended, it should be employed only where rivers are of large volume, and where consequently the new forms of expression, which come into operation during a low state of the water, are of relatively less moment. With these qualifications, I shall proceed to put down the terms of an equation for the velocity of the rivers in question. The principles are explained in page 40.

Given,—

The height of column h, 592 feet.
The length l, 3,696,000 feet.
The mean section of the Nile, $30\times3000=a$, 90,000 square feet.
The wetted surface 3060 feet.

To find a co-efficient for the velocity v, which in this case is actually 5 miles an hour=7·3 feet per second.

$$\sqrt{\frac{h.a}{l.s}}=\sqrt{\frac{592\times 90{,}000}{3{,}696{,}000\times 3060}}=\sqrt{\cdot 0047}=\cdot 069$$

$$\text{And } \frac{7\cdot 3}{\cdot 069}=105$$

$$\text{Whence } v=105\sqrt{\frac{h.a}{l.s}}$$

We may also test this theorem by the case of another great river.

Given,—

The height of column six inches to a mile: it being immaterial what h may be, provided l is taken in proportion.

The length, therefore, is a mile, 5280 feet.

The mean section of the Ganges, 50 × 5280=264000 square feet.

The wetted surface, 5280+50+50=5380 feet.

To find a co-efficient for the velocity, which in this case is something more than five miles an hour, say 7½ feet per second, instead of 7·3, as above.

$$\sqrt{\frac{h.\ a}{l,\ s}}=\sqrt{\frac{\cdot 5\times 264000}{5280\times 5380}}=\sqrt{\cdot 0045}=\cdot 067$$

$$\text{And} \frac{7\cdot 5}{\cdot 067}=112.$$

$$\text{Whence } v=112\sqrt{\frac{h.\ a}{l,\ s}}$$

The two results are not, therefore, materially different, being 105 and 112 respectively: the mean is 108·5: but we need not experience great compunction in making a round number of this 108·5: in which case the highest velocities of rivers in a flood state will be found by the equation.

$$v=100\sqrt{\frac{h.\ a}{l.\ s}}$$

Dimensions all in feet; and v in feet per second.*

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* Prony's theorem is as follows:—

$$v=-0^{m}\cdot 072+56\cdot 86\sqrt{\frac{A\ H}{S\ L}}.$$

Where A is the area of the profile.

L the length.

For the sake of curiosity we may here work out a question which is said to have embarrassed the old Pharoahs, and to have deterred them for many ages from completing the canal intended to connect the Mediterranean and Red seas; lest the Red sea, said to be at a higher level than the Mediterranean, should drown Egypt. Assuming the correctness of the premises—and it does appear that the level of the Red

---

S the perimeter or wetted surface of the profile.
H the fall corresponding to L.
V the mean velocity per second.
Dimensions in metres.

An example is given in which

The rectangular section of a canal is three metres wide, and $1^{m}{\cdot}10$ deep; length 150 metres; total fall $0^{m}{\cdot}075$. Required velocity?

Here $A=3\times1{\cdot}10=3^{m}{\cdot}30$.
$L=150$.
$S=3+(2\times1{\cdot}10=)2{\cdot}20=5^{m}{\cdot}20$.
$H=0^{m}{\cdot}075$.
And the answer is $0^{m}{\cdot}943$.

Putting all these dimensions into English feet, we have
$A=35{\cdot}52$.
$L=492{\cdot}14$.
$S=17{\cdot}06$.
$H={\cdot}246$.
$V=3{\cdot}094$.
$-0{\cdot}072={\cdot}236$.
$3{\cdot}094+{\cdot}236=3{\cdot}330$

$$\text{Then }\sqrt{\frac{35{\cdot}52\times{\cdot}246}{17{\cdot}06\times492{\cdot}14}}=\sqrt{{\cdot}0010407}={\cdot}0323.$$

$$\text{And }\frac{3{\cdot}330}{{\cdot}0323}=103$$

Whence the Theorem is

$$v=103\sqrt{\frac{h.\ a}{l.\ s}}$$

Notation as on other side.
The coincidence is remarkable

sea is about 30 feet above that of the Mediterranean—let us endeavour to show what the real effect would have been.

The canal could not be less than about 70 miles long: its fall would therefore have been say half a foot to the mile. We shall suppose its depth to have been 15 feet, and its width 60 : then we have

h .... ·5
a 900
l 5280
s 90

To find v.

$$100\sqrt{\frac{\cdot5\times900}{5280\times90}}=100\sqrt{\cdot00095}=100\times\cdot0308=3\cdot08$$

feet per second, or $2\frac{1}{10}$ miles an hour.

Presuming that there were no locks in those days, the effect of a direct communication between the seas would therefore have caused a constant current from the Arabian Gulf to the Mediterranean of $2\frac{1}{10}$ miles an hour, about the same strength of current that there is in the Straits of Gibraltar.

The equation in page 40, for the conveyance of water in pipes gives results very similar to that above drawn from the data of large rivers, when worked with the higher co-efficient of 48 instead of 43. Thus, the velocity in the example (note, p. 40) would, with 48, be 4·4. Let us then apply to the pipe the theorem $100\sqrt{\frac{h.\,a}{l.\,s}}$, and we have

h 150
a 1·767
l 26,400
s 4·71

$$100\sqrt{\frac{150\times1\cdot767}{26400\times4\cdot71}}=100\sqrt{\cdot00213}=100\times\cdot046=4\cdot6$$

feet per second, which is very near 4·4.

But, as before stated, it is only *in the case of rivers in a state of flood or full water that these theorems ought to be used ; to shallow rivers, with irregular beds, they are quite inapplicable.*

Fig. 18.

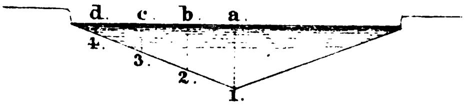


Fig. 19.

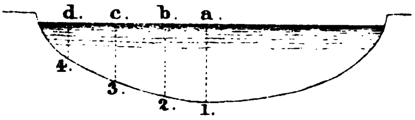


Fig. 20.

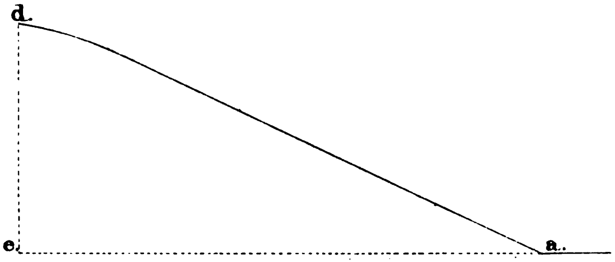


Fig. 21.

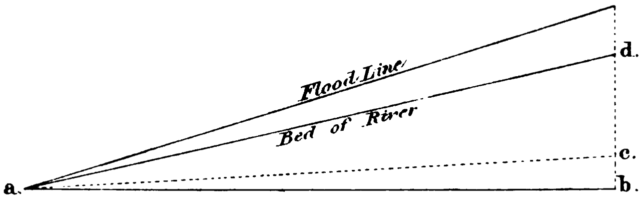
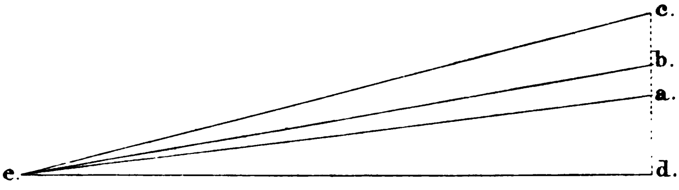


Fig. 22.



Amongst the circumstances connected with the resistance of river beds, are to be reckoned the sloping, or glacis-like form of their depositions. In rivers with a straight course, the beds are deepest in the middle, and gradually shoal towards the sides: for a particle of water 4 (*Fig.* 17) has more resistance to encounter from the sides of the river than a particle 3 more distant from them; a particle 3 experiences, in like manner, more resistance than a particle 2; and 2 than 1: a difference of velocity therefore ensues, in the same given time the particle 1 travels from 1 to *a*, 2 from 2 to *b*, 3 to *c*, and 4 to *d*; but the effect of this variable velocity is to cause a more powerful action on the bed in 1 *a* than 2 *b*, in 2 *b* than in 3 *c*, &c., and thus the water is deepest in 1 *a*, and gradually shoals to 4 *d*, so that the section becomes as represented. The section may in this case be disposed either in straight lines, or in curved lines, constituting a kind of half ellipse, the vertex of which is in the middle of the bed, *Fig.* 18, 19.

If the glacis be formed of gravel, we shall find the heaviest material towards the lower part of it, *a Fig.* 20. where the current is strongest; and the lightest towards the top, *d*, where it is weakest: if the material be fine, such as sand, then, as even a feeble current is sufficient to act upon it, the upper part of the glacis will be, on a comparison with gravel, more depressed, and the slope less rapid.

It is very seldom, even in straight reaches, that the channel of a river is in the middle of its bed: for either the current is, in the flood state—the governing state—too powerful for the resistance it has to overcome, in which case, as will presently be explained, a deviation occurs; or from some inequality in the bed itself, or a previous impulse given to the direction of the current, the thread or vein of water, indicating the deepest part of the river, is established elsewhere than in mid-channel. In reality, owing to the continual changes in the courses of rivers, the deepest water is far more frequently to be found near or close to, the sides, than in the middle: but more of this below.

It is evident, that whatever power is possessed by rivers beyond the force necessary to drift their materials, must, from the nature of the case, be neutralized. The question then arises why rivers, being self-regulating, really do possess any such extra power as they have been proved to do on a comparison of the height of motive column with the resistance of the debris carried by their currents, instead of being adjusted to the simple force required to transport those materials.

In answering this question, I shall again take the Nile by way of illustration: for clear examples must be procured where they are to be found. The due height of 16 cubits which this river is said to rise at Cairo, means that it rises to the 16th division, and something more of the Nilometer in the island of Raoudah: and as a part of the base is covered, in all states of the river, to about 3 cubits, the actual rise is not more than between 13 and 14 cubits: at a medium 13¾ cubits, equal to 24 English feet very nearly.*

In Upper Egypt the rise is much greater, being from 35 to 40 feet; while, on the contrary, at the outfall, there is no sensible rise. The height of the banks in each situation shews the rise of the river. In Upper Egypt they are from 35 to 40 feet high; at Cairo from 20 to 25; and at the sea they disappear.

Neglecting, then, for the present, minor considerations as to the exact line described by the surface of the water in its descent, it is evident that in comparison with the bed of the river, the flood waters present a triangular profile. It will also be recollected that the point where the greatest rise of water occurs is elevated 592 feet above the sea; so that the general profile may be represented as in *Fig.* 21.

Now, if the bed of the river had been flat, or nearly flat, then the flood waters might have risen in *b c*, until they acquired power enough to discharge themselves; and had there been no other state of the river, the matter might have ended here. But there is also a low state of the river, during which the waters have not power to discharge themselves along the nearly flat bed in question; on the contrary, they require a fall for their conveyance, and accordingly the bed of the river becomes raised for this purpose, to *d*. Upon *d*, then, rise the flood waters, instead of upon *b*, and as those waters have, by the hypothesis, sufficient power to discharge themselves along *a b*, or some line intervening between *a b* and *a d*, so it follows that at *d* they possess an excess of power, owing to the greater fall, and thus the proposition is made clear. As very different volumes of water are to be discharged, an arrangement of bed must be made to suit the *least* quantity as well as the *greatest.*

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* The cubit is 21·22 English inches.

Some further explanation of this flood column—a circumstance common to all rivers—may not be amiss: it is highest in the interior, up to some point where the occurrence of a fall or rapid constitutes what Grandi calls the equivalent origin of a river: from this point of maximum elevation its gradual diminution seaward is owing to the circumstance that on its downward course less and less resistance is continually encountered, inasmuch as the magnitude or developement of bed becomes constantly less between any given point of comparison and the sea. The resistance which the column has to overcome being thus reduced, the column itself is abated proportionally, until at the outfall it is brought down to zero. Where the volume is full and continuous, and not broken into streams and pools, the resistance must evidently be considered as a whole.*

---

* In carrying a barometer through the channels of mines, I have observed the same kind of change in the height of motive column as is here described. From the point where the air-current enters the mine, to the one of its issue, there is a constant fall of the mercury: in other words,

There is then a certain point *b* above the bottom *a*, ***Fig.* 22**, at which the water of a river can discharge itself with a continuous or unbroken current: in small rivers this point is not realised until they are in a state of partial flood; but in large rivers it is marked by the lowest state of their waters. If now, we are to compute the effect of an additional depth or column *b c* raised upon the former, as above described, we are not to compare the entire elevation *d c* with the entire elevation *a b*, because the portion *d a* from the horizontal line *e d* to the bed of the river gives only the zero of the scale at which the lowest waters begin to flow. We are therefore to compute from *a* as a starting point, and we have thus the relative motive columns as *a b* to *a c;* and, since the resistance is as the square of the velocity, the former and new velocities will be to each other as $\sqrt{a\,b}$ to $\sqrt{a\,c}$.

But the matter does not end here. As the flood waters rise, the relation between power and resistance is altered: the larger bed has not the same amount of friction as the smaller one; wherefore new terms must be introduced into the question, consistently with the observations made in pp. 40, 41, whence the whole expression becomes

$$v \propto \sqrt{\frac{d.\,a}{l.\,s}}$$

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the remaining resistance becoming less and less as we travel onward, its reaction is proportionally reduced.

Another analogy exists. When an air-current is *once established,* and the difference of temperature producing it is known, we can determine the velocity at another temperature, by a comparison of the temperatures only. Thus, suppose a velocity of four feet per second to be produced by a difference of 30° temperature; then, if the difference be increased to 50° we shall have the square of the former velocity to the square of the new velocity as 30 to 55; or, which is the same thing, the former velocity will be to the new velocity as $\sqrt{30}$ to $\sqrt{50}$; that is, as 5·48 to 7·07: whence $\frac{4\times 7{\cdot}07}{5{\cdot}48}=5{\cdot}18$ feet per second new velocity. Now, if for difference of temperature we put motive column, *a b*, *a c*, respectively, *Fig.* 23, then we shall have the velocities as the $\sqrt{a\,b}$ to $\sqrt{a\,c}$, corresponding with $\sqrt{30^\circ}$ and $\sqrt{50^\circ}$.

Where d is the depth of water at the point of observation,
a the mean area of cross sections to the outfall,
l the length or distance to outfall,
s the mean wetted surface.

Working this equation with the data of the Nile, we have

$d=45$
$a=90{,}000$
$l=3{,}696{,}000$
$s=3060$
$v=7\cdot3$

To find a co-efficient,

$$\sqrt{\frac{45\times90{,}000}{3{,}696{,}000\times3060}}=\sqrt{\cdot00036}=\cdot019.$$

$$\text{And } \frac{7\cdot3}{\cdot019}=384$$

$$\text{Therefore } v=384\sqrt{\frac{d.\ a}{l.\ s}}$$

It will be observed, that though the Tyne in flood has a much less aggregate rise than that of larger rivers, yet the rise of the Tyne, proportionally to its length of course, is much greater than in those rivers. The Nile, for instance, has, say 40 feet for 700 miles. The Tyne has 12 feet for only 18 miles, being twelve times as much as the Nile, in proportion to distance. The cause of this difference is the larger ratio of flood water in the Tyne, as compared with its ordinary state. In p. 26 it is shewn that the freshes of the Tyne increase its volume sometimes as 1 to 120; those of the Nile as 1 to 5 only.

We may bring the foregoing details to bear upon a curious circumstance connected with the great American lakes; the general surface level of which has been, by some cause, lowered at least six feet. The fact is well known, but not so the explanation: and I may therefore be permitted to suggest, that the continued shortening of the river's course from Lake Erie to the great falls is the cause of the depression in question. We have seen how the resistance of rivers is influenced by the length of their channels, and when the falls, which may be regarded as the terminus of the river with reference to its upper course, were situated 14 miles further from Lake Erie than their present distance of 19 miles, it is easy to see that a greater rise of water than is now necessary would be required at the upper end to propel the collected lake feeders through the channel of the Niagara; and as the height of this column fell, the lake surface would fall with it. Had all other circumstances been alike, we could have fixed the ratio of the respective heights of column in the proportions of $\sqrt{33}$ to $\sqrt{19}$, that is, as 5·74 to 4·36, which in the case of a river 30 feet in depth, would give a present depth of 23 feet; but as the conditions of resistance have increased by the general lowering of the surface of the river, the ratios of decrease of depth may be something less than those calculated.

As the course of the river shortens, the same gradually lowering process which is now going on will draw off the waters of the lake by degrees, and not with that sudden rush or debâcle which has been apprehended.

The relation of *little* experiments would be out of place, where an opportunity is afforded of drawing results from the great operations of Nature. It is only, therefore, for the purpose of illustrating the foregoing views, that I here cite some observations made in a mill-race, 24 inches wide, into which variable quantities of water could be admitted by means of a sluice. The length of channel from *a*, a point clear of the influence of the sluice, to *b*, the outfall, was 60 feet, and the different points of observation were, as marked, 1, 2, 3, 4, 5, and 6, at intervals of 10 feet, *Fig.* 24 The length, being constantly the same, is kept out of the calculation. The results are put in proportions of 100:—

	EXPT. 1.	EXPT. 2.	EXPT 3.
1. Volume	100	262	422
2. Mean depths	100	166	215

3. Depths at Station 1	100	222	311
4. Depths at Station 6	311	511	711
5. Mean sections (as mean depths)	100	166	215
6. Mean velocities	100	158	197
7. Wetted surface	100	114	124
8. Wetted surface, divided by sectional area	100	69	58
9. Squares of the actual mean velocities	100	249	388
10. Squares of mean velocities should be, if dependant on alteration of resistance only (8)	100	145	172
11. Numbers under 10, multiplied by depths under 4, of 311, 511, and 711, give ratios of	100	240	393

It will be seen that the last numbers approximate as nearly to those under 9 as can be expected from the nature of such experiments, and that the results are corroborative of the views advanced throughout this chapter. For example:—

1. With a double depth and a double section, we have a quadruple volume, while, for the same quadruple volume, the wetted surface increases only as 1 to 1¼: for as the receptacle becomes fuller, the effective resistance diminishes, while the power increases, so as to establish a double ratio in favour of the larger volume. In point of fact, the larger volume has an increased velocity, and the flood waters rise to produce this new velocity, the cause and effect adjusting themselves to each other: but as the waters rise the conditions of effective resistance are altered, and become less than before, whence the increased velocity results from two causes combined, the rise of flood column, and the diminution of resistance.

2. We perceive why rivers do not widen in proportion to their increased volume; because an additional velocity ensues, which deepens the bed: the same consequence follows at the confluence of two rivers as when a single river is thus augmented in volume. In applying this principle, a French

writer of the last century deceived himself by its very prominence : he affirmed that neither depth nor width increased by augmentation of volume. This was proving too much : and it is difficult to understand how he has made the mistake, unless his wooden troughs or receptacles were so short that the difference in height was imperceptible; for length is a main element of resistance, and the resistance of rivers with a continuous current must be taken as a whole, in their full length and developement. In the flood state this continuity of stream is always the condition of rivers ; but in a low state it is not necessarily so.

CHAP. V.

Structure of River Beds—Lake Basins along Lines of existing River Courses—Haugh Grounds—Sinuosities—Formation of Islands—Bifurcations—Deltas—Power of Currents to raise themselves to a higher Level, illustrated by Tidal Action.

It is a matter of common observation to find on one side of a ravine a particular mineral bed, which is also found on the opposite side, so situated, that an imaginary line would connect the two; in such a case we cannot conclude otherwise than that this stratum was once continuous across the valley, and that the intermediate portion, now wanting, has been removed by the agency of water. Sometimes the current which did the work still occupies its hollow. In other instances there are vast denudations of this kind which cannot be referred to the agency of existing streams.

But besides the irregularities of surface thus obviously occasioned by the action, existent or byegone, of running water, we are to contemplate inequalities of a more original character, the evidence of which rests upon the fact, that the strata are not, as a whole, lying either horizontally, or conformably with the curved lines of the globe, but possess an obliquity or inclination which causes them to appear at very different levels on the face of a country. The dip of the strata is also very variable; and in some high districts, of which we may take as a type the carboniferous lime rocks of Northumberland, it is very common to find a bed dipping into a valley and then rising again with the surface on the opposite side. It would here be out of place to go further into geological discussions than is necessary thus to convey the idea of a surface occupied by a number of basin-shaped hollows, and to explain, as briefly as possible, what has evidently been the original distribution of water along the lines of many existing river-courses; that, namely, of chains of lakes, with intervening rocky barriers, which have been worn down by the operation of waterfalls, to their present condition of river beds, or to that state of transition between a waterfall and a river-bed which constitutes a *rapid*; or, finally, which, among more refractory rocks, or on more recently elevated land, are still existent as waterfalls, significant of the process which has long ceased elsewhere.

The original bottoms of these inland lakes may be below the level of the sea. The modern alluvial "wash," for example, in the Derwent Haughs, extends to a depth of at least 100 feet beneath the outfall of the Tyne: in the valley of the Team the depression is still greater. It is evident that a river communicating directly with the sea, could not have flowed at so low a level; but there is no similar objection to the bottom of a lake being so situated, whose surface waters might also be borne up to a level much higher than that of the ultimate outfall. We are obliged, therefore, to have recourse to the assumption of a lake, to account for the simple circumstance here mentioned; and to complete the hypothesis, we may add, that the outfall of that lake was at Bill Point, the sandstone rocks of which have been cut through by the operation of its waterfall.

On examination, we shall find that the waterfall which has cut its way through a rocky barrier, or is in the act of doing so, has followed, or is following, the direction of least resistance. Niagara is an apt instance; that cataract has found a bed of shale beneath the limestone, and by working upon the less indurated substance, undermines the harder rock, until the latter, no longer able to sustain itself, falls into the pool below in immense fragments: and it is obvious that the cataract, in retreating towards Lake Erie, will follow the line of bearing, or, what miners call the water-level line of this shale bed, if the latter be continuous and uninterrupted by nips or faults; for if we can suppose the excavation to be attempted in a rise direction, the cataract will then arrive at some other and probably harder stratum, more difficult to be operated upon than the soft shale; and, on the contrary, if it cut towards the dip, the same result will ensue: therefore the line of bearing of the shale bed is the one that will be followed, as constituting the direction of least resistance.

In many excavations thus made by water through rocky strata, the lateral sections shew those strata in a horizontal position; because the beds are, in point of fact, most open to attack in the direction thus exposed: in other places, the intersection of a fault, and the disintegration occasioned by it, appear to have determined a passage for the current; and considerable bends often occur where the line of river bed has had to accommodate itself to these variable circumstances. The best illustration of the manner in which the breaching of lake barriers has been effected is to refer to what is now taking place, especially in elevated countries, for the lakes situated towards the outfalls of rivers, have, for the most part, disappeared; their barriers being the first that are worn down, on account of the larger volume of water which passes over them.

Bill Point (Tyne) has been mentioned as a notable instance of the position of a former waterfall; and I may here name another, that of the Rocky Gorge, at Countess Park, North-Tyne, where the cataract has not yet performed its full work. There are, in fact, many more along the courses of both Tynes, as well as on other rivers. A very remarkable one occurs on the Till, beginning at Wooler Haughs, and extending to Etal: the gulley caused by the former waterfall is strongly marked at Twizell Castle, where the direction of the river has been changed at a right angle, to enable it to cut through the rocky strata in the easiest direction, that is, along the line of the beds. The silt and gravel beds, which hang on the skirts of the hills bounding Milfield Plain, are remains of the deltas of tributary streams; while the flatness of the bed of the Till; the lightness of the materials composing that bed; the singular depth and stillness of the river itself; and its many windings, through sandy depositions, are all anomalies in a stream of its volume and position, reconcileable only with the fact that it flows through the bed of a former lake.

It is unnecessary to multiply examples of this nature. I shall only further observe, therefore, that the same arrangement presents itself elsewhere. Dwight counted eleven of these former Lake Basins on the River Connecticut, and several on the Hudson. This feature is, in fact, a common one of rivers: the seaward barriers have been for the most part removed, but of the interior ones many yet remain, and furnish an exposition of those which have disappeared.

Though a considerable space, or length of gorge, may intervene where the agency of water has cut through the barrier between one original basin and another, there is not any difference in principle as to the mode of action. The line of least resistance is still the line that is followed: but as this may vary greatly in the course of a few miles, just as the strata vary, as they are traversed by some great dislocation, or by the protrusion of some more refractory rock than usual, like the great Whin Sill near Barrasford; so the course of the river is also variable; and where there is a rocky bed we still have bends; but not properly windings. Where a bend does take place, it forms a new reach, rather than a winding, but in the reaches taken separately, there is not a great irregularity. For a similar reason, as the banks of rocky rivers are not easily acted upon, we generally find them steep: the rigid nature of their materials enables them to stand without sloping away to the talus or line of repose required by looser substances. Another distinction may be added: in rocky gorges the water is deep, *because the banks do not yield:* in other words, because the section is procured by depth rather than by width, of bed.

A lake formation of the kind in question, which discharges its water from basin to basin, implies that the lake surfaces have been at a higher level than the actual river. A river may, therefore, have had to work twice over upon the same materials; once when they were drifted by it into the lake, and afterwards when it carried them on a further progress, until its bed became lowered to the suitable line; so that where these lakes once existed, we shall now find that the river has cut through their depositions, and removed them by its action; and in this manner the lake bed has been handed over, as we may say, to the dominion of the river; but the original silt of the lake still covers the sides of the neighbouring declivities, or shews itself more prominently where the delta of a stream that brought in heavier materials at the original level, is yet to be seen, the brook itself having followed down from the lake to the river level with a rapidity proportioned to that with which the materials of the lake were re-excavated; so that we find brooks now emptying themselves into such former lake hollows with a very considerable degree of declivity in their beds. And thus we can account for the rapid falls and deep gullies of the brooks that join the Tyne in the neighbourhood of Newburn, where the beds of those streams more nearly approach to the declivities of torrents than the slopes of tributaries about to lose themselves in a river.

The sites of the former lakes under consideration are now occupied by what are termed haugh grounds, over which the river, in the course of generations, strays from side to side, first removing and then replacing, the depositions with great regularity: for when the current shifts to another place, its former bed becomes back water, and is silted up by a deposition which is finer in proportion to the stillness of the water, because only the finest mud can find its way where the current is nearly or absolutely tranquil; the coarser sedimentary matter having been already dropped before its arrival there. These haughs are therefore, fertile, and very uniform in their aspect, a circumstance due to the fact, that being the gift of the river, they are parallel to its flood surface: for if any depression exist, it is filled up by the extra deposition which takes place there, it being evident that the quantity of such deposition is, *cæteris paribus*, proportional to the height of water column above it.

Notwithstanding appearances, the haughs do not constitute a perfectly plane surface: being more elevated at the upper than at the lower end, upon the principle that the river establishes a certain degree of fall for the transmission of its *detritus*. Thus, if *l* be a space filled up by the depositions of the river whose bed is *a b;* the new surface is not the horizontal line *b c*, nor is it any other horizontal line *d e;* but a part of the line *f c*, parallel to *a b* the former bed, which is thus raised from *a* to *f:* so that *f c* shews the slope of the haugh grounds. *Fig.* 24*a*.

The shifting of river beds in low grounds is often productive of inconvenience as regards their drainage. Thus, if a bed formerly established, *Fig.* 25, against *e f* the solid declivity of a country, shift to *a b c*, the water which afterwards collects in *h* will not find its way along the line *h g* to the river, because *h g* is a level line, whereas to enable it to drift its debris, a current must have a certain slope of bed, as *i g*, *Fig.* 26: but as the latter line is above the surface level, the water must be conveyed in the direction *h c* to join the river at some lower point *c*, admitting of the requisite fall from *h*. Whence we find that where rivers thus change their courses, a brook *d c* is established to drain off the waters which cannot procure a more direct course to the river: and *d c* is often to be made artificially to prevent the conversion of that part of the Haugh into a marsh.

Fig. 23.

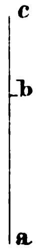


Fig. 24.

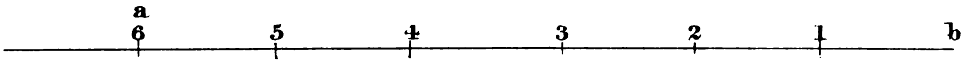


Fig. 24 a.

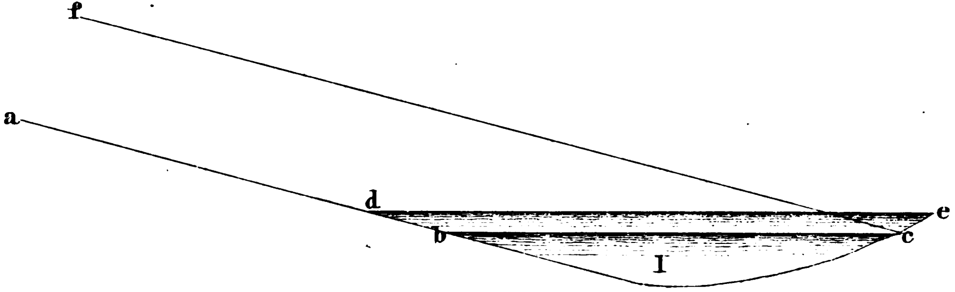


Fig 25.

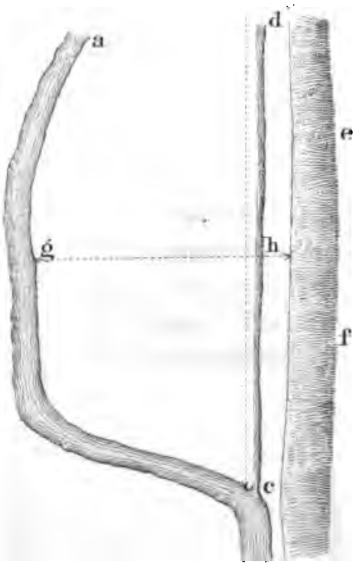
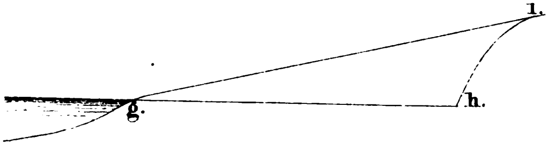


Fig. 26.



We have just seen that river depositions are established upon a certain line of fall; and that the shifting of the outfall of any stream to a greater distance than heretofore, thus renders an inclined bed necessary for the transmission of the debris throughout the new part of the course. If, then, such new portion of course happens to be flat, great difficulty is often experienced in conducting the waters to their destination. When, as in the case of the plain of Piedmont, the entire surface of the country consists of what is here termed Haugh ground, this difficulty is of proportionally greater magnitude, and has long puzzled the Italian engineers. In fact, a large portion of the Bolognese territory has been converted into a marsh by the tributary streams of the Po di Primaro, which wander over the plains in search of a declivity.

It is with the same principles in view that we are to contemplate the discharge of rivers having deltas, the growth of which causes a constantly advancing shore line. Let *a b*, *Fig.* 27, represent the sea, and *a c* the surface line of a delta: when, in the course of time, the outer line of shore becomes extended seaward to *d*, we are to calculate upon a new line of surface *d e* parallel and superior to, the former *a c*; and in this manner the interior portions of the delta are raised above the level of the sea, so as to become habitable: for it is evident that a given point *a*, is then no longer kept down to the sea level, but raised above it to *f*, the height of the vertical line *a f* corresponding to the conditions of the rate of fall and extension seaward: thus, if the fall be seven inches to a mile, and the advance of the outer line of delta has been 10 miles from *a* to *d*, then this implies an elevation of nearly six feet above the sea level, at *f*.

In rivers which periodically overflow their banks, an effect of the inundations is, to cause the grounds adjacent the river bed to rise to a higher elevation than the remoter parts of the valley. The reason is, that unequal quantities of sedimentare deposited according to the distance the inundation extends laterally, the matter in suspension becoming, for an obvious reason, less and less in quantity as that extension increases. But this operation must not be understood as causing a mound of sudden elevation on the banks of the river: on the contrary, as the overflowing waters purify themselves gradually, so the effect produced is that of a very moderate slope, the highest end of which is at the margin of the river, and the lowest at some distance—it may be, in the case of considerable rivers of this class, at the distance of several miles. Rennell describes very clearly this lateral depression in the Valley of the Ganges: that river seldom rises higher than about a foot above the marginal bank; and when this is the case, the depth in the lowest part of the valley is in many places 12 feet, being thus 11 feet of depression below the bank of the river. The waters of the inundation traverse this lateral space at the slow rate of ½ a mile an hour, while in the bed of the river, where the rate of fall, on account of the windings, is estimated at not more than one half that of the inundation, the velocity is, notwithstanding, from 4 to 5 miles an hour: a satisfactory illustration of what has been stated with regard to the motion of running water, as influenced by the height and continuity of motive column, and the diminution of effective resistance arising from depth of section. It is upon the same principle, that rivers of large volume have swifter currents than smaller rivers, with much greater declivities of bed.

We now also perceive the truth of the observation that inundating rivers, like the Ganges and the Nile, occupy the highest part of the valleys through which they flow. But the bottoms of these rivers, and even the ordinary surface of their waters, as distinguished from the flood surface, are much below the level of the depressed lateral tracts under consideration.

We may next turn our attention to the cause of sinuosities in rivers.

Fig. 27.

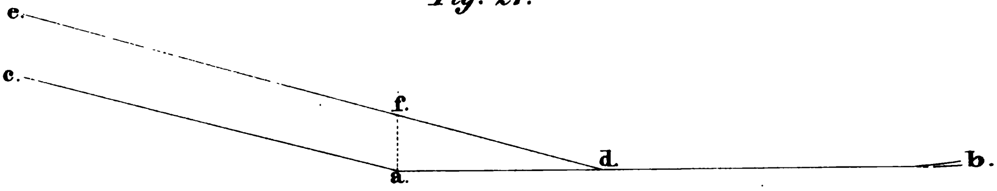


Fig. 28.

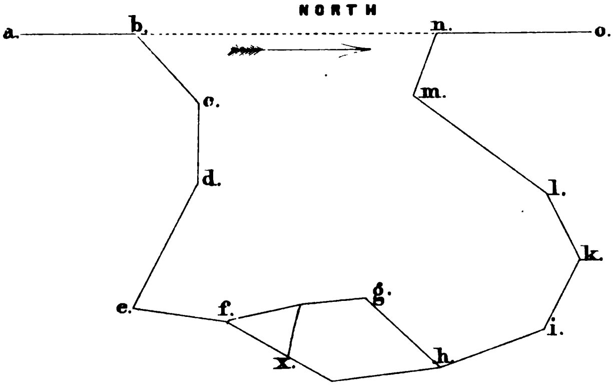


Fig. 29.

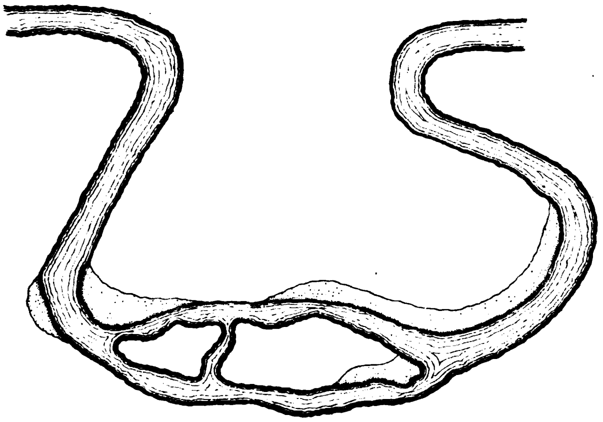
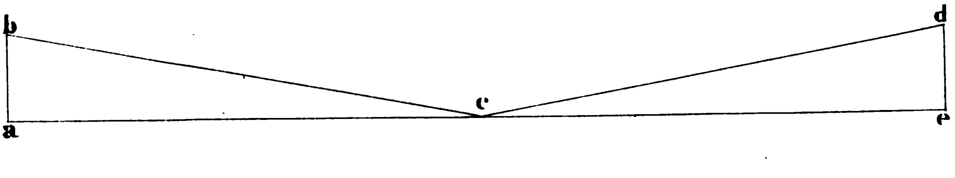


Fig. 30.



It will be remembered, that the flood state of rivers has been proved to be one in which the *power is in excess.* Yet the extra force thus in operation must, from the nature of the case, be neutralized down to that point which is required to convey the materials drifted by rivers. How then is the process of neutralization to be effected ? The action of a body falling from a height, is a vertical action, and accordingly the first effort of the current is to cut down into its bed; but this very circumstance destroys its progressive motion by effecting, as we may say, its own blockade. The principle of such destruction of motion is the same as that caused to the stream by its pool, or to the river by its boil ; and the operation on the bed being thus stopped by a counterfall, the action, which is the alternate one of that on the bed, viz., the lateral action, is commenced, and then the banks are acted upon—a lateral bend of the current ensues, and this constitutes the first stage of a winding. In *Fig.* 28, the arrow shews the line of greatest fall: and the question is why the current, instead of following that line *b n*, takes so large a circuit by *b e i n*: it is obvious that the entire fall from *b* to *n* is the same, whatever route we take between these two points; but as the circuitous route may be longer than the direct one in the proportion of say three to one, so the *rate* of fall in this direction averages only a third of the other.

In *a b* the current moves along the line of greatest fall, and, by excavating the bed, destroys its own movement: a lateral action is commenced along *b c*, but this is not sufficient, though now reduced to half the full rate of fall; accordingly the next movement is in *c d*, which has no fall: neither is this enough: the current ultimately takes the line *d e*, which has a counterfall, in order to put itself into equilibrium with its yielding bed.

At *e* the river meets with an obstacle which is, in fact, (for the figure is taken from Nature,) the solid and permanent slope of the country. But for the occurrence of this barrier, the current would have worked its way further in this direction, and turned round by a more gradual contour than the one we see: while the resistance arising from the extended length of such contour would have probably rendered the island *g* unnecessary, as a substitute for it.

However, as the river started at *a* from a solid bank, so it has another at *e*; the current is turned in the direction of the greatest fall *e f*: at the same time its impetus, or centrifugal force, causes it to cleave to the concave southern bank: while the bed is still operated upon by the direct force of the current. Here, then, are two distinct actions: that on the southern bank, and that on the bed; which last, by producing the lateral action so often mentioned, has the effect of dividing the current into two branches, and of causing the formation of an island.

In more familiar language, the river, on arriving at *e*, is met by an obstacle, for the time insuperable, the ancient declivity of the country: it is forced by this obstacle into the line of its greatest fall; but in that direction it works upon its bed, and by an action which may be termed self-destructive, thus checks its own forward career: its natural tendency is then to diverge to the north; but having brought with it an impetus from that quarter, it divides itself into two parts, and so forms an island. The effect of this division of the stream is to weaken it, and so we find that the northern current, becoming unable to cut more deeply into its bank, resumes the direction of greatest fall, and finally, by joining the other current, terminates the island.

We must not here omit to notice, that the southern current, which is much the most powerful, continues, even after the bifurcation, to work upon its bed, and so creates a resistance which obliges it to throw off a lateral channel at *x*, dry in a low state of the water, and forming a secondary, or *Presqu'-île*, at the head of the main island. This branch may be regarded as an attempted winding on the part of the southern current, with a view to escape from the process of *entérrement* or blockade, to which it is being subjected.

When the two channels re-unite at *h*, the joint current has considerable force in the direction *h i* of greatest fall, and accordingly works its way in, *i*, *k*, *l*, *m*, having in the latter a very considerable degree of counterfall, the explanation of which is precisely the same as that already given.

I have drawn the diagram with straight lines and angles for the sake of illustration: but there are not, of course, any such asperities in Nature. *Fig.* 29 is the real figure, of which the other is a skeleton: and in this state it is nothing more than a delineation of the course of the Tyne around Newburn Haugh.

We thus perceive that it is by means of windings and islands that Nature reduces the energy of rivers, the power of which *in a flood state* exceeds that of the resistance of their beds: and by parity of reasoning it follows, that by cutting off bends and throwing into one stream the separate currents that form islands or shoals (submerged islands) so do we, *pro tanto*, increase the energy of the current.

It would appear that where Nature cannot bring the bed and current into a state of equilibrium by windings, she does so by means of islands and shoals. Few rivers appear to have a wide enough lateral range to admit of the full developement of their windings: and it is observable that the antagonism derived from a counterfall cannot be carried beyond a certain point; because the current, in thus returning, as it were, towards its source, cuts so deeply into its banks, that an impediment is presently established to its further progress. If then the counterfall direction be limited, and the extent of winding also limited, by the width of river plain, then islands and shoals are substituted for windings.*

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* There are of course other causes of the formation of islands besides those assigned; accidental accumulations of trees, sunken vessels, or of other objects in the beds of rivers, may form any where the nuclei of islands: these, however, are not exceptional, but additional cases.

It is obvious that rivers of the largest volume, and those whose beds consist of the finest materials, must have the greatest windings. How great then, must be the bends of a river like the Amazons, of which Condamine says, that "For 1200 to 1500 miles below Borja, a stone, or a simple pebble, is as rare as a diamond; there are Indians here who never saw a rock, and who, when they come to Borja, collect stones as precious merchandise, until they find they are common, and then they throw them away." Of this great river, which intersects the finest part of South America, we know very little: but Lewis and Clark, (without quoting further authorities,) furnish some apt examples for the Missouri. In one of these, after a day's voyage on the river, they found themselves so near the point from which they had started, that they had the curiosity to have the distance stepped, when it was found to be only 974 yards, though the distance made by the boats was 18¾ miles. What was called by them the Great Bend, is a still more remarkable winding: the distance across the neck being 2,000 yards, while the circuit made by the river is 30 miles. Again: after a circuit of 12 miles, they found themselves at the distance of only 370 yards from the point whence they set out. They add, that when the water is high, this Peninsula is overflowed; it seems formed of the mud or ooze of the river; and they contemplated the probability of the current making its way through this short cut: "for," say they, "the sand of the neighbouring banks accumulates with the aid of that brought down the stream, and forms sand bars projecting into the river: these drive the channel to the opposite banks, the loose texture of which it undermines, and at length the river deserts its ancient bed for a new and shorter passage. It is thus that the banks are constantly falling, and the river changing its bed": and again they mention the frequent finding of old beds "quite dry, or without water except a few ponds."

The making of short cuts by the river does not, however, end with that operation; so long as the old channel, and new one, are both open, or so long as the old channel has not yet been silted up, so as to prevent the passage of even the larger flood waters, the short cut may maintain a straight line; but after the old bed is silted up, and the whole power of the current directed into the shorter channel of greater inclination, the winding process again commences; and in the course of time the winding thus established is exchanged for another short cut; so that this process, with its alternations of island and shoal, continues in a series constantly changing, and to which we can affix no limit.*

It may be remarked that the description given by Lewis and Clark puts cause for effect; they say that "sand banks project into the river, which "drive the current to the opposite banks." Whereas it is manifest, that these sand banks could not have rested in the situation mentioned, unless the current had been *previously* directed elsewhere. The sand is a deposition which .could not take place until the waters became relatively quiescent, where it now lies. Yet this pernicious confusion of cause and effect is the basis of the costly, and so often misapplied, system, of dredging.†

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* The Greeks, who personified every thing, have a story, that Hercules fought with the River God Achelous, who changed himself during the combat, first into a serpent, and then into a bull; having reference to the *windings* of the river, and the bifurcation, or *horn-like* branches of the Delta.

† The objection here made is to Dredging as a permanent measure. Locally, and as an adjunct, it may be useful or even essential, but as a system, it is unsound, in attacking the effect instead of the cause. We have already seen enough of the power of River Currents to justify the conclusion, that if properly directed, they are, in the lower courses of rivers, adequate to the work assigned to them. More expense may be easily incurred in Dredging out silt where it will be laid down again, than in the permanent improvement that would remove it entirely.

In the spring of 1849, the channel a hundred feet off the Cramlington Gears at Hayhole, was deepened by dredging, to 10 feet at low water. The Dredger was then taken away, and on its return nine weeks afterwards, there was one foot of water in the same spot; 9 feet of sand having been deposited in the interim.

The bifurcations which take place in deltas also furnish examples of the manner in which rivers establish the equilibrium of their beds: the current, now approaching the sea, experiences less resistance by the diminution of that element which constitutes length of channel; its power, therefore, compared with the resistance, becomes relatively greater; a lateral action is excited, which causes the division of the stream, into two branches; and in this manner restores the equilibrium. Upon the same principle minor bifurcations are formed to meet new conditions of equilibrium, and we are thus enabled to perceive, that the apparent labyrinth of creeks and branches towards the sea terminus of a delta is not an arbitrary or an accidental result, but one governed by fixed causes: in the midst of apparent confusion order is established by the operation of physical laws. Neither can we be at a loss to understand the formation of the lakes or lagoons which extend from the extreme points of a delta towards the interior of the country : for such lakes are, in fact, spaces yet unfilled up; the first operation of the river branches being, as before shewn, that of making the ground adjacent to their own banks the highest in elevation; each bifurcation therefore carries with it a tongue or buttress seaward; and the tracts, first of water, and then of marsh, *left behind*, are filled up afterwards. On the seaward side of these inlets there are often barriers composed of silt, which, having been drifted along shore by the marine currents, is lodged under shelter of the more projecting parts of the delta; and is heaved up by the action of winds and waves until it becomes dry, though pierced or breached in one or more places for the passage of the waters.

We may conclude this chapter by noticing a very usual, though remarkable, effect of tidal action in those situations where currents are excited by it; that is, in narrow seas, rivers, and estuaries, and along irregular shores.

The great rise of tide in trumpet-mouthed estuaries is due to the resistance experienced by the tidal current which sets into them. A current of water rises against an obstacle with a force proportional to its impetus, just as a wheel in motion surmounts an impediment opposed to its progress. But there is a peculiarity in the rise of liquids above the original level from which their impetus is derived, that does not obtain in solids. The utmost we expect of a spherical body rolled down an inclined plane is, that it will roll up another and opposite one to the same elevation: but fluids do more than this, and the nature of the action by which they do so is to be examined. By way of illustration we may put the case of the waters of a large lake being raised, as not unfrequently happens, six or seven feet higher on the leeward than on the windward shore, during a stiff breeze of wind: yet the force of such a wind is very far from being equal to a column of water six or seven feet high: on the contrary, a high wind blowing at the rate of thirty miles an hour, indicates a pressure of not more than eight or nine inches of water. How, then, is the larger column in the first instance produced, and then maintained at its level?

In the case put, of a solid spherical body rolling up an inclined plane, the impetus ceases at the bottom of the plane, and the body is no longer helped on its course; but immediately begins to experience the retardation which finally stops it. The action impelling the fluid is, on the contrary, a *sustained action:* so long as the current continues, so long is the anterior mass of fluid acted upon, or thrust forward by it: and the question is, not how far particles may thus be raised above a lower level, but whether the rate of inclination of the plane be so small as to allow the constantly-acting impetus of the current to neutralize and overcome the gravitating force of the particles. For example: the height of column due to a current of three miles an hour is about four inches; and such may be regarded as the power which, in this case, is at work on every part of the plane, and whose operation in extending it is limited only by extraneous circumstances arising out of the resistance encountered by the fluid, or the intermittent nature of its action. In reality, the power which is possessed by a current thus to raise itself above its level, is, when we come to investigate the subject, found to be considerable. In the instance quoted, a fall of 4 inches *a b* corresponds with a horizontal distance of 4½ feet, whence we have the triangle *a b c*: and constructing *c d e* equal to *a b c*, we have the plane of ascent *c d* rising at the rate of 1 in 13½, *Fig*, 30. It is not meant that such cases actually occur, because there are practical impediments, as before mentioned, to the full operation of the forces: nevertheless, the capability of even a moderate current, thus to raise itself up an inclined plane by the sustained nature of its action, is a very notable circumstance, explaining away, perhaps, difficulties not yet accounted for. If we observe the position of those estuaries which are noted for the greatest rises of tide, it becomes obvious that they open upon the main ocean in such a manner as to receive the full force of the great tidal wave, and that they have also magnitude enough to admit an incline plane whose length is very considerable in proportion to its height. The Bay of Fundi has fully 150 miles for the length of this inclined plane; and indeed much more, if we reckon the northern portion of the Bay of Massachussets as contributing to the action. And the estuary of the Severn has very nearly the same length of 150 miles, reckoning from a line drawn from the Land's End to St. Bride's Bay; though even these are hardly its outside limits, since the configuration of Irish coast also tends to direct the great tidal movement of the Atlantic into this estuary. The tidal flow is therefore lifted up to the height of 60 feet at Chepstow, in the British Channel; and to the extraordinary height of 120 feet in the Bay of Fundi; though the rise in the Gulf of St. Lawrence, 40 miles distant from the latter across the Isthmus, is only eight feet.

The great tidal action which would, if free to do so, circulate round the globe from east to west, along with its governing luminaries, is thus broken and diverted by intervening barriers of land, and by sub-divisions of that land, until all traces of its original course are lost, and it is found to travel, in some parts of its career, in a direction the reverse of that originally marked out for it. The local actions of the tide are not less variable and remarkable according to the greater or less obliquity of its action on the coast lines; the depth of water and nature of the bottom: whence the great difference in the rise of tide on our own coast, and which, in localities closely adjoining each other, is hardly less remarkable than in the great examples already quoted. Upon the principles explained the tidal water piles itself, as may be said, against particular shores, and not against others. The local operation of this principle is so extensive, that it must be received as a part of the doctrine of the tides. By its means we are to explain the great variation in rise on different parts of our coast, not merely from 60 feet at Chepstow to only eight at Yarmouth Roads, but even between adjacent points of the same line of local shore.

It will be recollected, that though the proper tidal action consists of a wave, and not of a current, yet the tidal wave establishes its level in narrow seas and rivers by means of currents: even in these cases, however, there is a wave, as well as a current, and both causes concur in the manifestation of the tides.

CHAP. VI.

Principles deduced—Non-elasticity of Water—Bed of Tyne from Bill Point to Collingwood Memorial—River Beds require regulation—Are to be taken as a whole—Lateral receptacles injurious—Jarrow Slake—Necessity of solid Banks—What portions of the River are the least necessary to be interfered with.

In the numerical details and statements of the following chapters, reference is made, except when otherwise mentioned, to Rennie's Plan of the Tyne, the one most suitable for the purpose of this memoir, the object of which would, in fact, be best carried out by taking examples and illustrations from the river in a natural condition, but as this state of things, *ab initio*, cannot now be realized, Rennie's Plan is preferred as approximating more nearly to it than recent surveys.

The reader's attention may also be here called to the fact, that though the *governing* principles are drawn, for the reasons given in page 23—, from the observed operation of currents moving in one direction; yet the reciprocal action of tidal currents, and the characteristic results of that action, are, wherever needful, fully introduced and illustrated in the remaining portions of the memoir.

We are then to deduce, from the investigations made in the previous chapters, the following general principles and their application:—

1. *The actions of river currents on the bed and banks are alternate actions.*

Thus the vertical action on the bed at *a*, *Fig.* 31, occasions a counterfall: the current is then diverted: in *a b c* two forces

Fig 31.

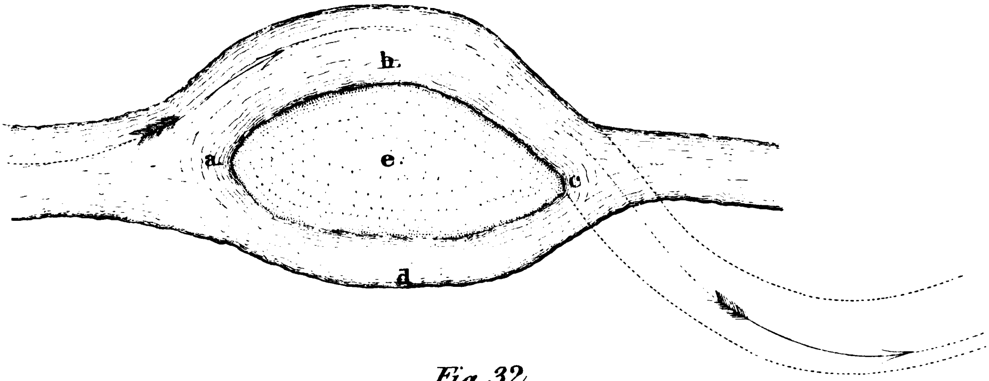

Fig 32.

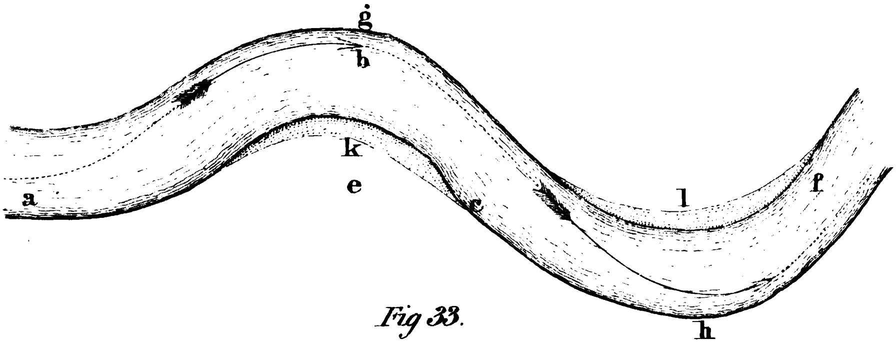

Fig 33.

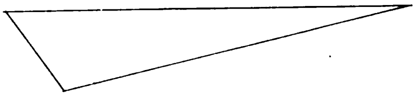

Fig 34.

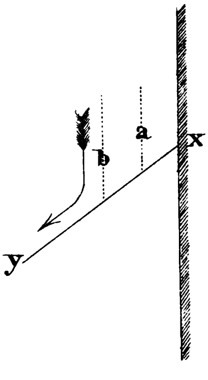

Fig 35.

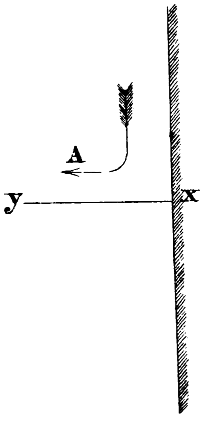

Fig 36.

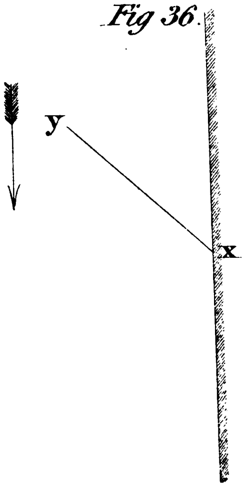

Fig 37.

are at work, one in *a b*, which tends to excavate the bank; and the other is the opposition of the bank to the process of excavation. If then, that opposition be sufficiently powerful, the curved line *a b c* is the resultant of the two forces. In like manner may be demonstrated of *a d c*. The inner space *e* then becomes either an island or a shoal: in other words, a river bed that is too wide becomes convex in the middle.

It is thus, that the tendency to an accelerated movement in river currents occasions irregularities in their beds, and variations of width along the lines of their courses: for this alternate widening and narrowing is a successive process: by the resistance of the banks the currents are again brought together, and at *c* the same operation recurs as at *a*. If one of the divided currents happen, as is frequently the case, to be more powerful than the other, then the feebler current *a d c* may be silted up, and the entire discharge will pass along *a b c*, *Fig.* 31: but in this case the river will not adjust itself in a straight reach *a c*, but will form an opposite and corresponding curve *c f*. We shall then have deep water at the sides *g h*, and shoals at the points *k l*, *Fig.* 32. The section, in this case, approximates to an obtuse angled triangle, one of whose sides is very short and disproportionate to the others, as shown in *Fig.* 33.

It will be observed that the traversing of the current from one bank to another, is the consequence of a particular impetus given by its previous direction. Water, being entirely non-elastic, does not rebound from a surface which is struck by it: but, on the contrary, establishes itself against that surface with whatever energy its current possesses. If the river edge be corrodible, a curved bank is thus formed, the resultant of two forces, one of which endeavours to act upon the bank and the other opposes that action, and in this way a new direction is given to the current: but the application, to the movement of water, of such phrases as "rebound," "resilience," &c., implying a degree of elasticity, is manifestly incorrect.*

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* So determined is this disposition of a water current to set itself against an obstacle, that if such obstacle be refractory, the current will take a circular, or even spiral movement, before changing its direction, and in this manner often digs out deep holes adjacent to an incorrodible bank.

As a specimen of the errors which have been committed, from the want of a due regard to the constitution of water, we may notice the faulty construction of weirs, or more properly speaking, jetties, erected for the purpose of protecting river banks. It was long thought, and proved too, by mathematical demonstration, that the right position of a weir is an angle of 45° with the under bank, as shewn in *Fig.* 34. For, it was reasoned, if the weir be made at a less angle than 45°, this will cause it to be of an inconvenient length : while if it be made at a greater angle, the impulse or stroke of the current against it will be so much the heavier; and so weirs had to be constructed at this angle. When they failed—as they did fail—it was thought that they had not been made strong enough, and additional fortifying, and deeper piling, were employed in their construction : still they went to ruin. In point of fact, the constitutional properties of water were omitted to be taken into account : however true it may be that the impulse of water is *as the square of the sine of the impinging angle*, this is not the real question. Neither, as has been stated, is water at all an elastic body : a particle a or another b does not rebound when it strikes the surface $x\ y$: both establish themselves, on the contrary, along that surface : so that the set of the current is from x to y, and this becomes in consequence the deep part of the river, instead of what it was intended to make it, the shoalest. Again, as regards the impact of the current, it is evident that when a weir is constructed at right angles to the bank, as in *Fig.* 35, still water is established in A, so that the impulse of the current does not reach the weir at all, but acts upon the body of fluid thus interposed. Finally, in this rectangular jetty, an eddy current may still be established along A against the fore part of the weir, as shown by the bent arrow; but this is prevented by turning the line of weir up stream as $x\ y$, *Fig.* 36. In the foregoing remarks, allusion is more particularly made to those cases where the current sets always in the same direction; where for example river banks are to be defended against the operation of land floods. It is also evident that jetties intended to increase the depth of water in navigable rivers are parts of a system, and offer many additional, and even different aspects, from those concerned merely in the protection of banks.

When a river acts on one side of its bed only, a sand bank grows on the opposite shore, and is attached to that shore: but in the case of tidal rivers, the reverse action of the young flood tends to isolate those sand beds, by cutting a channel through them near the shore: since it is along the shore line that the first flood makes its way, because it meets with least resistance from the down stream in that situation. Such is an origin of swatchways in tidal rivers; one of the mischievous consequences arising from that double action which ensues when the young flood is not able to face the still powerful remnant of the ebb.

Let us next apply this first principle to the lower valley of the Tyne. From Bill Point to the Collingwood Memorial, the Tyne flows over an ancient alluvium, often covered by its own depositions, and attaining, opposite Howden and Burdon Main, a thickness of nearly twenty fathoms beneath the bed of the river, as proved by the shaft sections of the collieries. From this central and deepest portion, the alluvium thins out in both directions, westward to the coal sandstone at the point above-mentioned, and eastward to the red sandstone which is associated with the magnesian limestone, and constitutes the cliffs of the Promontory of the Spanish Battery at the outfall of the river.

The alluvium occupying the basin described, is composed of sand, gravel, and clay; but in the greatest proportion, of clay, containing pebbles and bowlders, many of which are limestone of the carboniferous lime: others are basaltic, and more rarely rounded fragments of granite are interspersed. In the clay are frequent in-puts of sand, which contribute to loosen its texture.

I am fully disposed to attach to the character of the lower valley of the Tyne, as just described, a considerable influence on the form and condition of its bed. There is not here a rocky chasm, like that of the Bristol Avon; nor a long extent of gently falling country, such as the one in which the

Severn adjusts its bed, by means of many windings, to the action of powerful currents. On the contrary, the solid slopes of the country preclude the Tyne from winding, while the comparative facility with which the alluvial banks are acted upon, occasions the adjustment in question to be effected, by the process of *widening its bed.* It must, indeed, appear evident that the case is precisely one in which occur a widening and shoaling of the bed for the purpose of accommodating the resistance of the channel to the power of the current.

And the fact is really so. It is observable that seaward of Bill Point the bed of the river widens very fast, and with this widening, extensive lateral and central shoals make their appearance. The mean width of the high water bed from Newcastle to Bill Point is 546 feet, while in the next 1½ mile, extending from Bill Point to Hebburn Quay, the mean width is 1022 feet: at the Cock Crow Sand, which is the widest part of the river, the width is 1980 feet.

The principle here laid down is in fact the same with that so fully explained in p. p. 20, 21, &c.

2. ***The flood or high water state of Rivers is their governing condition, and the beds of rivers viewed as a whole, are the results of the highest state of their waters.***

I have already fully explained the nature of this proposition, which is not less true in its general application than with regard to the particular case of those rivers which, existing only in the state of flood, have yet their beds very distinctly formed.

If the quantity of waters discharged by rivers were constant, much less irregularity of bed would be experienced. But on the contrary, that quantity is extremely variable. We have seen for example, that the land waters discharged by the Tyne differ, accordingly to their highest or lowest state, in the ratio of not less than 120 to 1 ; and as the discharge of the least quantity is equally necessary with that of the greatest, so the beds of rivers, as we find them in nature, require regulation to meet those extremes, more especially in cases *where the variations of volume are very considerable.*

In rivers which are without tides, the largest volume of water is discharged during land floods: but in tidal rivers the joint effect of land floods and ebb tides is to be regarded as the condition of highest water.

During a heavy land flood, the velocity of the current of the river, in the channel off the new Quay, in Shields Harbour, at three quarters' ebb, is from 6 to 6½ miles an hour. When there is no fresh in the river, the velocity is, in the same situation, from 2½ to 3½ miles an hour. In reality, land floods are to be regarded as the principal scouring agents of rivers like the Tyne, the channel, or deep-water gutter, of which everywhere coincides with the strongest set of the ebb, or *downward current.**

3. *A river bed is to be taken as a whole. We have seen how the resistance encountered by a river current is, when*

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* Without theorizing at large on the formation of Bars, we may notice the well-known effect of land floods in deepening that of the Tyne, so as to cause a difference of two feet and upwards after freshes, as compared with a continuance of dry weather, especially if the latter be accompanied by easterly winds and high seas. These circumstances tend one way in shewing the marine origin of the Bar. The fact, that the Bar becomes deepest at the period when the greatest quantity of silt is brought down from the land, is fatal to the supposition of its river origin. It would seem that the sand, drifted along the coast by marine currents, is lodged on the Bar, for the same reason that it rests on the Herd, of which, in fact the Bar forms a portion, and that the river is, in all its states, antagonistic to this deposition; but it is only during the prevalence of its most powerful currents that it succeeds in deepening the Bar below that mean level which is the combined result of all the actions.

The doctrine of the river origin of Bars has probably arisen from a too hasty generalization of the subject, as illustrated by the formation of deltas; but the latter really constitute a distinct case from the one wo are considering, being due to depositions where there are no marine tides or currents, or those of such small moment, as not to have sufficient power either to carry away the river detritus, or to transport quantities of silt along their own lines of coast.

the stream is continuous, transferred from one part of its course to another. Within the limits, therefore, of the tidal flow, and still further in the case of land floods, our views of amelioration must be co-extensive with the entire developement or length of course.

There arises here a very important consideration. As rivers adjust their beds to a particular rate of fall, it would seem, at first sight, that we have no more to do than to lower the bed at the outfall, to produce a corresponding effect upon the bed in the interior of the country, since a new bed parallel, by theory, to the old one, and having the same rate of fall as before, would be established at a lower level, thus effecting by means of a process of a relatively simple character, that which is *the object of all river improvement, the depression of the bed or bottom to a lower level.*

Mere theory is in favour of such a result, and it would appear, from the excellent memoir of Mr. Murray, that the practical results at a neighbouring port go far to substantiate the conclusions of theory: that gentleman says, "By comparing the river in its present state with what it was in 1737, it will be seen that the average surface of the bed between Biddick and New Bridge, has been lowered 5 feet 3 inches." And again, "The engineering operations in the Wear shewed that a river might be much improved at a distance from its confluence with the sea, by simply deepening the outfall." It is right to add, that according to the same memoir, extensive dredging operations have been carried on in the last two miles of the river's course.

We must not allow ourselves to be deceived, either by theory, or by a single example like the one just quoted. In the structure of its bed, and the nature of the country through which it flows, the lower valley of the Wear differs materially from that of the Tyne. The Wear, in fact, in the district in question, passes through a ravine, and presents, in a natural state, an approximation to that structure of bed in which the appliances of Art may be considered as superseded by Nature. It is for this reason that the Wear, with a basin of less than 500 square miles, admits the tidal water to a greater distance inland than the Tweed, with nearly four times the extent of basin.

It is further obvious, that the result experienced in the Wear cannot, in all cases, ensue, for were it so, rivers having no bars, would not require internal improvements.

So, far, therefore, is the particular instance of the Wear from militating against our views of improvement throughout a river's course, that this case, when fully explained, is highly corroborative of such views, and enables us more distinctly to perceive the necessity of regulating by Art, the beds of those rivers which are not, like the Wear, already to a certain point, adjusted by Nature.

The example of the Wear is further useful in shewing, that all the circumstances must be taken into consideration with a view to arrive at a correct judgment of the particular operations required for the improvement of rivers. Under this aspect, *each river offers itself as an individual case*, to which general principles are still applicable, but which may also require the application of these principles in a greater or less degree, according to its distinctive character.

4. *Lateral receptacles, which become occupied with tidal water, are injurious.*

Allusion is here made, not only to Jarrow Slake, and to those minor slakes, as they may be called, at the Coble Dean and Willington Gut, but likewise to all other lateral irregularities, which do mischief by appropriating a portion of tidal water, and by producing eddies and other causes of reaction, which tend to thwart the operation of the current in its legitimate sphere of action on the bottom.

In this case the real question is, not whether Jarrow Slake and other loops of the Tyne be beneficial to that part of the river which lies seaward of them, but whether these loops or the higher portions of the Tyne, be the proper receptacle of the tidal water, having in view the upper, as well as lower, divisions of the river. Now the quantity of water in Jarrow Slake, at the full height of a spring tide, is about 2,300,000 cubic yards, while if a level line be drawn from the bar to the bottom of the river at Newcastle Quay, we shall find, on making the proper admeasurements and calculations, that there is above this line a solid content of nearly eleven millions of cubic yards of silt encumbering the present bed of the river, to which we may safely add, three or four millions more for the depositions westward of Newcastle Bridge, making in all *fourteen millions of cubic yards in substitution of the two and a quarter millions of Jarrow Slake.* It need not be doubted, therefore, that the proper tidal receptacle is the bed of the river itself, and that we are moving in the right direction when endeavouring to make it so.

It has been remarked that the flood tide in the river increases in velocity at half tide, that is, just when Jarrow Slake is beginning to be covered, but this is not a circumstance peculiar to the Tyne; on the contrary, it is a commonly-observed phenomenon upon the English coast. In connection with the Tyne, therefore, it amounts to no more than this, that the current of the flood tide is checked by this large inlet precisely at the time when its operation is calculated to be most beneficial.

The effect of Jarrow Slake in retarding the progress of the flood tide up the river is rendered very manifest by an inspection of a plan of the Tyne: and the accumulation of sand in the bed of the river here is made still more obvious when shewn on a plan which exhibits only the deep contours at low water. From such a plan, when the really useful portion of the bed is laid down, that namely, which has four feet and upwards of soundings at low water, spring tides, we find the bed of the Tyne opposite Jarrow Slake consisting entirely of sand, excepting a narrow channel near the Hayhole shore. We also see distinctly how the flood tide endeavours in vain to cut its way through the sand: and it is remarkable enough, that in this practical point of view, there is, attached to Jarrow Slake, and in the very bed of the Tyne, an extent of sand bank equal to nearly half the area of the Slake itself.* It is thus that the mischievous consequences of such inlets make themselves apparent on the spot. Neither does the evil end here. On the contrary, the loss of energy thus sustained by the current at a particular point, affects the river, as has been shewn, throughout its whole course.

Allusion has been made to the retardation of the flood tide in its passage up the river, as a consequence of the Jarrow Inlet: we have traced to the same source the encumbrance of bed in its immediate vicinity; and by the latter cause the ebb tide is also retarded: the tidal water is impounded: the duration of the ebb is prolonged: and the free entry of the next flood is restrained. Were it not for the class of obstacles under consideration, there would be no necessity for the flood tide creeping along shore in the manner it does, too feeble to turn the undischarged and still powerful current of the preceding ebb.

In a chart of the Tyne, the four feet low water contour between Jarrow Slake and Bill Point, occupies almost exactly a fourth of the bed of the river: while the eight feet contour occupies rather less than a thirtieth, or about twenty acres, amidst upwards of 600 acres of sand. At the Cock Crow Sand there is an interruption of even the four feet contour for about 380 yards: while that of eight feet presents throughout the space mentioned, a collection of straggling pools, realising the condition fully explained in the previous part of this memoir.*

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* The mean height of this single sand, as described, is very nearly six feet above the level of the Bar, and its cubical content is 1,182,000 cubic yards, being just half the water content of the Slake itself at spring tides. At neap tides, a considerable portion of the Slake is bare, even at high water, so that as a scouring agent for the Bar, its effect is really nugatory at the time when it is most needed, that is, when there is least tidal water in other parts of the river.

I have remarked upon the injurious effects of lateral expansions of the bed. These expansions may, in fact, be regarded as the results of a morbid action, since they are the substitutes for the legitimate operation on the bed in a vertical direction. It is not, therefore, with a view to particular inlets only, but also to the entire unregulated course of the river, that the objection applies. The same objection is to be urged against open jetties and half tidal walls, which have the effect of withdrawing a portion of the tidal water from its proper sphere of action on the bed. We are not to suppose that because the reservoir of supply is inexhaustible, an indefinite quantity of tidal water will enter a river; on the contrary, the river is in this point of view, really a conduit into which a quantity of water enters *proportional to the resistance on one side, and the pressure or head of water on the other;* the question is also one of time, commensurate with the duration of the moving force. If, then, the latter be obstructed by lateral recesses, the due action upon the bed is thereby prevented, and not only do we gain no additional tidal water by means of such recesses, but we lose that which the unrestrained action of the current would have produced in the bed of the river itself, together with the beneficial consequences resulting from the deepening of the channel. In making changes, we are to establish a new order of things, and not to mix it up with an old one, the defects of which have already been proved. *Solid banks* are manifestly requisite, in order to secure the action on the bed, for without preventing the operation upon the banks, that upon the bed cannot be maintained. In point of fact, unless the sides are incorrodible, *there is no such agency as a continued scouring agency:* the only effect is to dig holes in the bottom, succeeded by corresponding shoals, or, in other words, to cause a succession of pools and shallows, such as we see abundantly exemplified in the existing bed of the Tyne.

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* See Map A at conclusion.

Having thus endeavoured to prove that no well-founded apprehension of an *ultimate* loss of tidal water need be entertained from the shutting out of the Jarrow and other indentations, I may proceed to answer another alleged objection to the enclosure of these receptacles. It is said that the water abstracted by Jarrow Slake, lessens the impetuosity of the current during heavy freshes, and thus contributes to the safety of the vessels lying in Shields harbour. This objection, if valid, would be of less moment now, that regular moorings are laid down, but it is difficult to conceive how any such effect can result, for the highest land floods of the Tyne do not, *per se,* occasion a rise of more than about four or five feet at Jarrow Slake, owing to the nearness of this part of the river to the outfall, whereas eight or nine feet of rise would be required to enable the water even to commence flowing over the Slake. It is, therefore, by the joint action of tide and fresh, that the water is raised to the level of the Slake, and this again occurs when the flood tide meets the fresh. In other words, it is during the operation of *flood tide* that the Slake, in this case, gets filled: during *the ebb,* the receptacle cannot contribute to reduce the velocity of the current, but rather the contrary, on the same hypothesis: in neither case is it, therefore, of service.

5. *The object of river improvement is to lower the bed.* We have already seen the necessity of regulating the beds of rivers, with a view to meet the very variable conditions of volume and consequent energy of current. Neither are we at a loss to comprehend the nature of such regulation: for as the actions upon bottom and banks are alternate actions, and the object is to depress the bottom, so it follows that to attain this end, the action on the banks must be prevented. Let us then endeavour to apply this principle to the Tyne.

Rennie states, that the area of the river between Shields Narrows and Newcastle Bridge is 1,694 acres, but this includes Jarrow Slake, so that the real area of the bed of the river, within high water mark, is about 1,344 acres, of which that eminent engineer proposed, it must be admitted in a somewhat summary way, to reduce exactly one-third, by means of the line of jetties laid down by him; the whole expence of his contemplated improvements was estimated at 519,320*l.*, for which large sum we were to expect an improvement in the interior part of the river, and an additional depth of about 2 feet upon the bar.

The propriety of embanking, in the way proposed by Rennie, so large a proportion of the river's area may well be doubted, and a sufficient discrimination does not appear to have been made between those parts of the river where a restriction of the bed is obviously required, and others not so situated. The upper portion, for example, from Newcastle Quay to Bill Point, is already either naturally, or artificially, so formed as to approximate to a requisite condition. The Sandhill, and the entire length of Newcastle Quay, are built within high-water mark; the same may be said of the Low Street at Gateshead. Many other wharf walls are also erected on the North and South shores, and the ravine itself is not greatly dissimilar from that which the Wear has been described as flowing through in the lower part of its course. It is not denied, that works of a particular kind may be required in this part of the river, but there is not the same necessity for them here that there is further down; and it must be recollected, that improvements made elsewhere, will have an effect upon this portion of the bed also.

In like manner, as regards that portion of river lying eastward of Whitehill Point, it is submitted that the Coble Dean ought to be shut out, but it is not apprehended, that, in the first instance at all events, further ameliorations might be necessary. The alterations proposed to be made at *the outfall, and those also proposed westward of Whitehill Point, cannot fail to have a material effect upon the insand, and other obstructions in this most important part of the river.*

The removal of certain projecting points, such as Whitehill Point, and Hay Hill Point, has always been a favourite topic in connexion with the improvement of the Tyne; and it is doubtless a safe engineering principle, that such removal would be to a certain extent beneficial, but we are not told in what degree the benefit would accrue, nor whether the advantage wonld be commensurate with the cost, and with the possible injury to the channel of that part of the river, which commences at the high end of South Shields, and extends the entire length of that populous town, including the shipping places of Manor Wallsend Colliery, and the Brandling Junction and Pontop and Shields Railways. It is not perhaps difficult to draw mere engineering lines of improvement along the course of a river, but the real question should be, how to attain the greatest amount of improvement with the least possible sacrifice of existing facilities and interests.

The mischief occasioned by Whitehill Point, has, it is to be feared, been already accomplished to an extent that is now, practically speaking, irremediable.* Casting our eyes along the South Shields shore, we shall find that from the Brandling Staiths to the Half Moon Stairs, a space of not much less than three-fourths of a mile, a bay or bite has been formed by the action of the current which sets over from Whitehill Point; and as the full strength of the ebb tide now sets directly into this concavity, the young flood is compelled to creep along the North shore, and all the mischievous consequences of a double channel, and deposition of sand due to a channel of too great a width, are here realised. But how is this state of things to be improved by the removal of Whitehill Point? Are we to expect that the Durtwick Sand will be swept away by such removal? Granting this to be so, is it not evident, that a shoal will immediately attach itself to the south shore within the bay above described? So obviously would this result ensue, that we can lay down an approximate line for the extent of the shoal, whose greatest width would be about 300 feet at the Steam Ferry Landing.

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* See Map B at conclusion.

Such anticipated results must demand a pause before the determination to remove Whitehill Point is carried out. As a question of relative importance, when we reflect upon the condition of the actual *bed* of the Tyne—how it is alternately furrowed, *hommocked*, and twisted—the advocacy of the removal of a few shore projections is, in comparison, really like straining at a gnat, and swallowing a camel.

Double channels are at present occasioned by the struggles of the flood tide to enter the river. But with a proper adjustment of the bed, there would no longer be a quantity of impounded water *to protract the duration of the ebb, and thereby prevent the entrance of the young flood.* The tendency would be for both currents to move in the same channel; and this important point would therefore be in a great measure realized, without that stricter regulation of the banks which is implied by the removal of projecting points and the inclosure of concave shores.* It is also ob-

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* According to Dubuat's results, the resistance arising from one sinuosity is trifling; it is when they come to be multiplied, that we are made sensible of the effect produced. By his theorem, $\frac{v.^2 \quad s.^2}{3000}$ where v is the velocity of the current in inches, and s the sine of the angle of incidence he makes the additional head or charge required to overcome each bend of the Seine ·05208 of an inch, but there are several thousands of these bends in that river's course, so that the entire augmentation of fall due to the bends amounts to above 27 feet, though he admits this to be, as he says, "*une evaluation fort en gros.*" In English feet, the above theorem is $.00375\, s.^2\, v.^2$

Dubuat observes, that sinuosities are means employed by nature to establish the velocity of equilibrium. Yet this velocity, or *regimen*, is really vious, that a great and complicated variety of vested interests is opposed to the too rigid application of such a principle. As regards the staple commodity of the district, it may be said, that so long as the banks of the Tyne are made use of as shipping places for coals, it is necessary to have deep water adjacent to those shipping places. The time will probably arrive—and that at no distant date—when we shall have floating docks on the Tyne; but even these cannot be made available for all parts of the district, or for the convenience of the various collieries that are widely scattered on the banks of the river.

Taking the times of low water at various points in the tidal basin, we shall find that the flood tide has at present to struggle against an average of 3 hours 38 minutes of ebb remaining in the river, and this circumstance may be cited in answer to those who dread the bringing of the ebb into conflict with the flood, as a consequence of narrowing the channel; a main object of such narrowing being, in fact, to facilitate the discharge of the ebb tide, and so to remove the very obstacle in question. At the same time, it is easy to conceive, that the effect of partial alterations may be to cause a more direct collision of the currents in the immediate locality of those alterations, without diminishing the general duration of the ebb throughout the river; and thus a case arises similar to the predicament in which the Tyne is actually placed, and which may account for the temporary deficiency of tidal water alleged to have been experienced. Indeed there must, in this point of view, be a diminution of tidal water during the progress of improvements of the kind

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no quality of rivers, when considered in all their conditions. On the contrary, as it is their function to transfer materials from the land to the sea, so the absence of a principle like the one mentioned, is essential to their character, and has no existence during that state of flood, which we have endeavoured to explain as the governing one of rivers.

under consideration, until the duration of the ebb tide is diminished commensurately with the extent of such improvements.

In concluding this chapter, I may remark, that I have applied, to the different divisions of the river above noticed, the tests of relative resistance detailed in Chapter IV., with the following results, at *half Tide*:—

Supposing the entire resistance from Newcastle to the Narrows to be represented by		100
Then the resistance of that part of the channel which extends from the Narrows to the East end of Jarrow Slake is represented by	9	
That from the East End of Jarrow Slake to Bill Point by ..	63	
That from Bill Point to Newcastle by	28	
	——	100

For equal lengths of channel, the resistances are as 1, 2½, and 1½, respectively, in the same order.

CHAP. VII.

General Conclusions—Lowering of the Outfall—Piers—Herd Sand—Narrows—Velocity of Tidal Wave—Attainable Velocity of Tidal Wave in the Tyne—Lines of Improvement—Distribution of Tidal Water—Resistance of Tyne Bridge—Upper Tidal Portion of River—Summary.

THE entire subject thus narrows itself to the following considerations:—

1. The improvements that may be effected at the mouth of the Tyne.

2. Those which may be made in that part of the river which lies between Bill Point and Whitehill Point, a space of about five miles.

3. What is to be done with the upper tidal portion of the river, extending from Newcastle to the Stella and Newburn districts.

1. There are at present portions of the inner bed of the Tyne at as low a level as that of the bar. Such is the case, for example, with the channel off Newcastle Quay. I do not mention other situations, where the channel is still more depressed, because such depressions may be due to local action; still it is well worthy of notice, that even in the upper tidal districts of the river, at Lemington and Stella, there are certain portions of the bed of the Tyne at as low a level as the bar. Confining our present attention, however, to the tracts below bridge, it may be remarked, that the channel, or deepest part of the river, from Newcastle to St. Peter's, may be considered, as being, on the average, at the level of the bar; from St. Peter's to Bill Point it is a good deal below that level; beyond Bill Point commences a structure of river bed which causes it to be raised, as far as Howden, above the

level of the bar.* From Jarrow to the Narrows we have a considerable depression; and again a rise to the shoal water of the bar and inner bar. Within the district described then, we find that the Tyne, on a general view, is convex in its longitudinal section, the apex being at the Cock Crow Sand—an anomalous profile, constituting a depressed space at each end, and what Guglielmini would have termed a *mountain of sand* in the intermediate tract.

Let us next direct our attention to the tidal surface. It appears from the various trials which have been made, that the levels of high water at Shields and at Newcastle, are sensibly the same. And further, it would seem from levels made above Bridge, amongst which I may include some taken under my own directions, that the level of high water at Stella is as nearly as possible the same as that of Newcastle. At Newburn the high water surface is a little raised, but not more than 8 inches or a foot above its level further down. We must, therefore, assume that the high water line of the Tyne is, practically, a level line, a circumstance not very common; there being, generally speaking, an elevation of the tidal surface in rivers and estuaries, explicable on the principles laid down in p. 78, &c. However, we must take the fact as it is.†

The circumstances just mentioned, and many others which come under notice in the course of this memoir, concur in shewing that *the outfall of the river ought to be lowered as the basis of further operations.* Situated as we have seen the interior portions of the river bed to be, it is, in reality,

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* The reader will bear in mind that the data are from Rennie's Plan, excepting where otherwise stated. See p. 82.

† I may here state, that I cannot of course vouch for the *close accuracy* of the figures given by myself relatively to this part of the river; but some pains have been taken in procuring them, and I believe them to be very nearly accurate. The approximation to the Bar level, of portions of the *bed* of the Tyne as far up as Blaydon, suggests itself as a reason for the non-elevation of the tidal surface in the inner parts of the river.

by deepening the outfall, that we are to acquire the energy necessary for the success of remedial measures elsewhere.

In order to clear our views on the subject, let us examine into the origin of the Herd Sand. It will be observed, that the promontory of Tynemouth extends about 1,600 yards eastward of the meridian of the high banks on the southern shore of the river; the whole of which extent of nearly a mile is, on the south side, occupied by sand, either dry, or with only a foot or two of water upon it, at low tide. When we regard the circumstance of the remarkable dissimilitude in the formation of the two shores, and reflect upon the quantity of silt which is drifted by marine currents, it becomes evident that the Herd Sand is a deposition beneath the shelter of the opposite promontory, a deposition which ceases so soon as its sea line is sufficiently advanced to be brought in contact with those currents, however it may be made to fluctuate within the governing line in question by the variable actions which are brought to bear upon it.

And here another consideration arises. The flood current which enters by the "Wheel," is a reverse current, affecting the general tidal direction as far south as Bent House; and in passing over the Herd, it brings with it *into the river* very large quantities of sand. The process by which sand is laid down on the Herd is thus one *constantly going on:* since by the removal of one portion, another is provided with room to replace it. If the sand so brought into the river be discharged, or partly discharged, by the ebb tide, it is again, together with that arrested in its passage along the coast, laid down upon the Herd: and thus a kind of circulation is thought to be maintained of the most mischievous character imaginable.* In continued dry weather, it is evident that more sand is received from the sea than is discharged into it, especially when high seas act as an obstacle to freedom of issue at the outfall: whence the deterioration of the bar in such seasons, to the extent, sometimes, of 2 feet and more. On the contrary, during freshes, the river, by its additional power, discharges more sand than it receives; the bar is improved, and we are thus made aware of the agency of land floods in establishing that function of rivers by which they are made to dismiss more debris than they receive, when a balance, as we may say, is struck between the two accounts.*

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* I purposely say, "is thought to be maintained," because, while reasons of the description cited in the text, have a certain force in the actual state of the River, it is yet manifest, that as sand can only remain in a river or estuary under circumstances which admit of its being lodged there, so it follows that far more importance is due to the condition of the

The insand, and the bar itself, are really parts or extensions of the Herd, which constitutes one great shoal at the mouth of the river.

How then is this state of things to be remedied? Would the erection of a north side pier, determine a current of sufficient strength to keep down the bar? I apprehend not,

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tidal receptacle than to the mere fact of sand being brought into it; for, if such condition be a right one, the sand will again be discharged. It is not, therefore, properly with the view of checking the ingress of sand, but with that of *conducting and maintaininy the energy of the issuing current*, that a pier across the Herd is recommended in the sequel.

* At Newburn Haugh the low water surface is about 9 feet above the low water surface at the bar when the river is in the ordinary state, but during floods the surface at Newburn Haugh is sometimes elevated 15 feet, making a total height of 24 feet above low water surface at the bar: so great is the extra power derived from land floods, besides the diminution of effective resistance arising from greater depth of section in the upper portion of the river. The result is sufficiently manifest in the increased velocity of the current. In the example at p. 87, the joint power of land flood and ebb is shown to be at least quadruple that of ebb only. For near the outfall, a high land flood and ebb together, travel at the rate of above 6 miles an hour, while a spring ebb moves no more than 3 miles an hour. Now the relative power of the two currents is much greater than their relative velocities, being in fact as the squares of those velocities (Chap. IV.) Therefore, the swifter current has in this case not merely double, but *quadruple* the energy of the slower one: and commensurate effects are produced as well upon the bar, as on the interior sand beds of the river.

since a leading cause of mischief would still exist. In reality, a north pier would constitute an extension of the Tynemouth promontory, which would be followed out by a corresponding advance of the Herd Sand eastward, upon the principles already explained.

I may here remark, that I have no wish to put the case of North Pier *versus* South Pier, and the contrary; my own opinion being, consistently with the principles laid down in the previous part of this memoir, that works of this nature at the mouth of the Tyne will not prove satisfactory in their results until piers are constructed *on both sides.* A north pier in connection with a southern one, might prove indispensable in preventing the division of the ebb current; but when taken *per se*, it is submitted that such north pier cannot have the effect desired, so long as the south side remains open.

As a principle, it is obviously desirable to extend a pier to that point where the force of the along-shore currents is decidedly manifested: and in this respect there appears to be a defect in many of the designs hitherto framed for the improvement of the mouth of the Tyne. In order to realize the condition just stated, it would be advisable to carry out the works, at all events, to that point where the northern line of coast opens, for it is not until this point is reached, that the configuration of the shore admits of the tidal currents being strongly felt. Nor is it even there that their full agency comes into operation: for the line which is drawn from the face of Tynemouth Cliff to Cullercoats is not a clear line of deep water: it is, on the contrary, broken by many rocky points. Yet Rennie's original pier terminates 150 yards short of it, and the recent pier, proposed by the Corporation of Newcastle, is also short by about 105 yards.*

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* Mr. Brooks' original North Pier was, however, designed, I believe to be carried further out than any other yet contemplated, the pier head being meant to extend into 14 feet water. I may add, what is, indeed,

On the Map B, at the conclusion, are traced designs of piers, in accordance with the foregoing views: they are carried out 200 yards beyond the line in question. I should wish them to be more, but the practical difficulties of construction and consequent increase of expense, are for consideration. Yet great cost is too frequently incurred in such undertakings for a totally inadequate object, by stopping improvements just where they ought to begin; and no form of expenditure is so useless as this. It is to be hoped that the Tyne Commissioners will not limit their proceedings to partial amendments, such as that of obtaining two, or three feet more water on the bar than at present, but that they will take a much more enlarged view of their duties in connection with a river which has so great a capacity of improvement, and is, at the same time, so well able to bear the burden of that improvement as the Tyne. These gentlemen, we may expect, will not be satisfied with less than 12 or 14 feet on the bar at low water, spring tides, and will probably furnish their engineer with a datum accordingly for the basis of his operations.

I may here remark, on the subject of expense, that it is surely not too much to expect, that the land and more valuable frontage to be acquired in the interior parts of the river will be worth, at all events, the cost of inclosure; and if this view be correct, then the cost of the piers will constitute much the largest portion of the expenditure on the works contemplated in this chapter. Without, therefore, going into detail on the subject—in fact, the requisite data for doing so properly, are wanting—it may yet be advisedly stated, that the entire cost of carrying out the improvements in question will probably be a good deal short of the gross sum estimated

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apparent from the foregoing statements, that I concur with that gentleman in thinking a North Pier desirable, without, however, joining issue as to its utility in comparison with a Southern Pier.

by Rennie, assuming the expenses of the interior alterations to be defrayed as above mentioned.

A space of 1,200 feet is left per plan, at conclusion, between the piers; which is about three times the extent of opening at Sunderland. It is conceived that an ample supply of water will pass through this opening. Indeed, comparing the relative amount of resistance as at present, and on the supposition of the piers being constructed, we may calculate, that the wetted perimeters divided by sectional areas respectively are, as 2½ to 1 nearly in favour of the piers at first quarter flood, and at half tide about 2 to 1 in their favour; differences quite sufficient to meet any extra resistance arising from the augmented velocity due to the narrower, though deeper, section.* Besides, the resistance of a river must, as has been shewn, be taken as a whole; and the augmented velocity which thus occurs at only one point of its course becomes therefore very fractional, when considered as spread over its whole extent. Indeed, by means of straight piers, such additional velocity will probably not exceed, or even equal, the amount of obstruction created by the present conflicting currents which enter the river at different angles, so that the advantage of a straight course, and a uniform tidal current in both directions, are a balance remaining to the credit of the piers. These circumstances are mentioned to shew, that we need not apprehend a deficiency of tidal water ensuing upon such a change at the outfall as the one contemplated.

The consideration last named is of importance enough to merit some further investigation. Let us then observe in what manner the tidal waters enter the Tyne. A spring tide begins to flow about 2h. 20m. at the Prior's Rock, before it commences to do so at Newcastle. But during this period of 2h. 20m., it rises about 8 feet at Prior's Rock. Now, the fall of low water surface from Newcastle to Prior's Rock is 3ft. 6in., which, being deducted from 8 feet, leaves 4ft. 6in., as the elevation of the tide at the outfall, above the level of the water surface at Newcastle, at the time of tide specified. It follows then, that when 8 feet of flow has taken place at the outfall, there is a large portion of the river, at, above, and even below Newcastle, which has not yet felt the tidal influence. Now one of the inferences we are to draw from the case just put is, that the mouth of the Tyne is not favourably situated for the admission of tidal water, the entry of which is, on the contrary, an affair simply of *hydrostatic pressure:* and thus probably we may account for the absence, in the Tyne, of the elevated form of tidal wave, which is found in estuaries open to the direct tidal action, and even in those rivers, the estuaries of which, without receiving so direct an impulse, are yet spacious enough to create an impulse of their own, the momentum of which extends itself to the inland waters. But what is chiefly worthy of attention is the circumstance that the facilities for the admission of tidal water are not likely, on the grounds stated, to be diminished by the construction of piers at the mouth of the river, for if we are to assume that the tidal action, in this case, is one of mere pressure, then the rest is a question of resistance, in regard to which it has been already shewn that the resistance arising in a channel between piers 1,200 feet apart is not so great as that due to the actual passage of the tidal waters over the straggling shallows of the bar and its associated sands.*

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* The admeasurements on which this calculation is founded are taken from Rennie's plan. The perimeter of the wetted surface is, at half tide almost exactly a mile at the entrance, and the mean depth is 10 feet at the same time of tide.

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* The "Narrows" are, in fact, the true mouth of the River, their structure being such as is due to the action of *a current which forces its way through a sand bank.* For example, if the ultimate line of level be *a b*, *Fig*

In those cases where a falling off in the amount of tidal water has been experienced after the erection of piers at the outfall, the cause of that deficiency resides, it is conceived, greatly in the circumstance that the inner portions of the river have not been simultaneously improved, so that the tidal water of the ebb continues to be impounded, and, by pressing towards the outlet, retards the free admission of the young flood. Such a cause is suggested as more feasible than that of a supposed want of room at the entrance, in those cases where the contraction from piers occasions, as instanced above, less resistance to the influx than does a passage over extensive shoals.

In laying down the piers, I have adopted, from several designs, such portions as appear best suited to answer the purpose, particularly as regards the protection of the harbour from swell. The South Pier and inner wall are from the design lately before Parliament, with some material alterations: the pier, as delineated on the Map, being 300 feet south of the one mentioned, and extending, as already stated, 900 feet further out. There is also another alteration of an important description, the head of the inner wall being advanced 1,200 feet seaward, while the same extent of opening, or wave trap, is left by shifting the angle of the principal pier an equal distance in the same direction. This alteration is made to prevent a tendency to shoal between the head of the inner, and the cant

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37, then an obstacle *f*, representing the sand bank referred to, causes the water to rise from *a* to *c*, thus forming the raised surface *c d*. The water thus raised forces its way through the bank, and falls to the fixed level *a b*, along the line *d e*: but *d e* is a line of declivity; the velocity of the current is accelerated in flowing down it, and this increase of velocity causes a *narrowing and deepening of the section*.

"Narrows" are by no means peculiar to the Tyne, but are common in other bar rivers. It will be seen, that the same figure and explanation serve to shew the manner in which the pool or basin inside the Narrows is formed.

of the outer pier, the probability of such an occurrence being obviously greater when the inner pier stops short with a wide expanse on both sides, than when it is carried forward to a point abreast of the Black Middens, and of that continuous rocky shore, which will serve to determine the direction of the current on its way to the outer piers.

As regards the relative position of the piers, I confess myself unable to perceive any sufficient reason for not making the head of the north pier upon the same parallel with that of the southern one, and they are accordingly so arranged.

In concluding this head, it would appear an omission not to remark, that the works at the mouth of the river would require, to render them complete, the enclosure of the Bite east of Clifford's Fort—a situation long projected for the construction of docks. It is, however, beyond my purpose to enter into this part of the subject.

2. The time of high water at Newcastle rather exceeds an hour later than at Shields; the velocity of the *tidal wave*, therefore, is about nine miles an hour; its velocity in the Thames is nearly 21 miles an hour, from the Nore to London Bridge; in some other rivers of even smaller volume than the Tyne, it is from 20 to 30 miles an hour. And as the velocity of the tidal wave *depends upon the condition of its receiver*, we are thus made aware of the inferiority of the Tyne in this particular, comparatively with many other rivers. The mean velocity throughout the whole tidal basin of the Tyne, is nearly 10 miles an hour; but at half tide it is only 5 miles an hour, and at first flood only 3 miles an hour; thus further indicating the utility of the tidal wave when applied as a test of the state of rivers, not merely at high water, when the crest of the wave traverses the river, but also at other periods of tide. Indeed, it is necessary to take those other periods, as well as that of highest flood, into consideration when applying the tidal wave as a criterion.

It has been shewn that a spring tide rises 8 feet at the outfall before its influence is felt in the Newcastle division of the river, and this, it may be remarked, is the period of the strongest flood tide. Then commences the process of filling Jarrow Slake, and the further exhaustion of the column in this operation. The final result is, that when it is high water at Newcastle, the tide has already fallen, for the space of more than an hour, at the Bar.

It is scarcely necessary to remark, that the obstacles which oppose the current of flood, also impede the progress of the returning tide, and so place the young flood in collision with the downward current of the impounded ebb.

We are not, however, to suppose, that the duration of flood and ebb can be made equal in different parts of the river; on the contrary, as the tidal change in the condition of rivers is accompanied by the actual transfer of fluid from one place to another, so that fluid, being in motion, is subject to the laws of resistance, and the further we advance up a river, the less is the duration of the flood, and the longer the duration of the downward current. Thus, at the Prior's Stone, the duration of flood is nearly 6 hours; at Newcastle, 4½ hours; and at Newburn, only 1½ hour. The comparative durations of the ebb are exactly reversed.

By increasing the velocity of the tidal wave, it is evident that we shall have an additional quantity of tidal water in the river, and that quantity will be discharged in a shorter time. The efficiency of the scouring agency will, therefore, be increased in a double sense:—1st, from the additional volume of tidal water; and 2ndly, from the greater energy with which that volume will operate.

A period of half an hour for the progress of the tidal wave between Shields and Newcastle is to be regarded as an object which is quite capable of attainment. The velocity required in this case, of 18 or 20 miles an hour, is, as we have seen, realised in the Thames, and in even smaller rivers than the Tyne itself.

The velocity of the tidal wave is here taken at high water, but to appreciate the full effect of an increase, its velocity at lower terms of tide must, as we have just seen, be also considered. For example, if the differences in the times of first flood between the bar and Newcastle, can be shortened from 2 hours 20 minutes to 1 hour, then the advantages gained are manifestly much greater than might be inferred from a comparison with the relative velocities of the tidal wave at high water only.

Throughout the course of this memoir, I have endeavoured to sustain the principle, that by *lowering the bed, we deal with all the causes of mischief at once.** Keeping this object in view, we have seen, that it is requisite to enclose Jarrow Slake, and that large spaces must also be enclosed at Willington, the Cock-crow, and Walker Sands. And here, I may repeat, that when the word inclosure is made use of, it is not implied that rubble walls, or half tidal walls are to be employed for such purpose, but that a solid structure of quaying or embankment, rising above the height of the highest waters, is to be erected The exclusion, to the extent required, and, we may add, in the first instance only, of a certain portion of tidal water, by such solid structures, is really not worth mentioning, compared with the object in view, which is, that of forming a *much more extensive reservoir in the bed of the river itself;* while, on the contrary, the effect of open, or partially open work, is to withdraw a portion of the power from its proper function of scouring the bed; and the eddies created by lateral receptacles, have an additional effect in retarding the progress of the current, and in preventing the establishment of the tidal receptacle in its proper situation.

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* It will be in the reader's recollection (Chap. IV.), that whenever extent of wetted surface is reduced, there is a corresponding and positive reduction of resistance. If additional depth ensue as the natural consequence of such restriction, still that additional depth or pressure, other circumstances being alike, causes no increase of friction on the bottom, owing to the *incompressible nature* of liquids. With solids the case is different. By additional weight, more of their particles are brought into mutual contact, and an increase of friction ensues. The remarkable distinction here noticed might of itself guide us a long way in the right line of river improvement. For example, if from the general expression in p. 40 $V. \propto \sqrt{\frac{h.\ a.}{l.\ s.}}$ we omit h and l, then $\frac{a}{s}$ is equivalent to Dubuat's hydraulic mean depth d; the cross section divided by the perimeter of the part in contact with the water. Whence the velocity of a river, when other circumstances are alike, is as $\sqrt{d}$.

We thus perceive how rivers, of large volume, may have greater swiftness of current than smaller rivers with a greater fall, as mentioned in p.p. 42, &c. where the alteration in the terms of resistance, accordingly as the volume is greater or less, is fully explained.

It may be added, that the velocity of the tidal wave depends, *cæteris paribus*, upon volume, and more particularly upon depth; in other words, as stated above, upon the condition of its receiver. Though the motion of the wave may therefore be regarded, in one sense, as independent of the currents of a river, yet to increase its velocity, and to improve the depth of water, are obviously correlative results.

If, however, we could have begun *de novo*, it appears to me that suitable improvement lines might have been drawn without encroaching on the bed of the river to the extent shewn by the works of the late Conservators: for it is evident, that in dealing with width of channel, the new power acquired by depressing the outfall must be taken into consideration. Another prominent feature is the shutting up of the Jarrow Slake, indentation: and under these altered circumstances, it might not improbably ensue, that we should rather have to guard against any additional enlargement of bed, than to contract the bed as already formed, excepting in the very worst situations. Influenced by these and similar considerations, I should have proposed to cut off from the river a smaller aggregate area than hitherto contemplated, the total extent of inclosure being, independently of Jarrow Slake and Coble Dean, 190 acres, or, with Coble

Dean, 218 acres. On the north side of the river, the line of inclosure would have been, excepting at and near Hay Hole and Whitehill Points, inshore of both Rennie's and the late Conservators'. Thus, at the Heaton Staith it would have been 162 feet within the Conservators' line, at Wallsend Staiths 210 feet, and at the west end of Willington Groin 102 feet within the Conservators' line. On the south side of the river the line would nearly have corresponded with Rennie's, but at Jarrow Quay it would have coincided with that of the Conservators.

The lines just described would have borne out the principles laid down, and at the same time attained other views as well as merely engineering ones, by interfering as little as perhaps circumstances admit, with the valuable commercial facilities afforded by the existing shores of the Tyne.

I feel called upon here to observe, that in laying down lines designed, as has been explained, under circumstances and views differing from those contemplated during the execution of a portion of the plans of the late Conservators and their Engineer, it would not be fair, and is certainly far from my intention, to impeach those plans. As regards particular parts of them, such as the contraction of the waterway at the Black Staith to something less than 750 feet, without approving of the degree of contraction that has been made in that situation, it is yet obvious that the channel of a straight reach ought to be more contracted than one with curved lines, for, in the former case, it is difficult to prevent the current of the river passing from side to side, while a concave shore, on the contrary, determines the line of deep water against itself.

On the annexed Map B, are delineated in red, the improvement lines, which, it is assumed, are yet open to be carried out. In laying down these lines, I have followed the principles advanced in this essay, while endeavouring, as before stated, to maintain at the same time, a consistency with interests which are manifestly of too great importance and value to be disturbed.

3. Of the total quantity of tidal water occupying, according to Rennie, the bed of the Tyne during a spring tide, I have calculated the local distribution to be as follows:—

Parts of River.	I. Tidal water in parts of 100.	II. Proportionate volume passing through each district.	III. Cubic yards of water corresponding with Column I. Millions.
Narrows to Jarrow Slake ...	19·4	100	6·
Jarrow Slake	7·4	—	2·3
East end of Jarrow Slake to Howden Gut	14·8	73·2	4·6
Howden Gut to Hebburn Quay	22·8	58·4	7·2
Hebburn Quay to Bill Point	10·6	35·6	3·3
Bill Point to Newcastle ...	11·0	25·0	3·5
Above Bridge	14·0	14·0	4·4
	100·		31,300,000*

It thus appears that there is only 14 per cent. of the whole body of tidal water above bridge.

It may fairly be assumed, that this deficiency will be partly remedied by the contemplated improvements in the *lower*

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[*] It is, however, presumed, that the calculation of the gross quantity of tidal water, as here given from Rennie, requires some correction, inasmuch as the river is not, at the *same period of time*, full in every part, up to high water mark. Thus, when it is high water at Newcastle, the tide has already fallen an hour at Shields, representing in spring tides, above three feet of ebb. Were the correction extended to tracts above bridge, the difference would of course be still more marked. In distributing the entire quantity of tidal water, the proportions in each division of the river enumerated, have been calculated from the respective areas and mean rises of tide, and are therefore relatively correct, but the *gross quantity* exceeds, for the reason given, by nearly one-twentieth the volume of tidal water at any one time in the river during ordinary spring tides, between Newcastle and the bar. Were the calculation extended, on the same principle, to the whole tidal course of the river, the correction would require to be about one-eighth.

parts of the river, which, by causing less exhaustion of the tidal energy, will leave a larger balance to operate upon the upper portions: and thus an additional scouring agency will be furnished, and a larger space established for the reception of the tidal water.

But we are also to enquire into the capabilities for improvement of the upper portion of the river, now under consideration.

The following data are collected from various sources:—

	Distance from Bar.	Fall of high water surface.		Fall of low water surface.		Fall of Bed.		Average fall of bed per Mile.	
	Miles.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
At Ryton	19	1	7	15	0	18	0	0	11½
Newburn Fishery	17½	1	0	11	5	14	0	0	9¾
Newburn Haugh	16¾	level		9	0	10	3	0	7½

If, then, the river, considered as a whole, have its channel improved in the manner contemplated, under heads 1 and 2 of this chapter, by at once increasing the energy of its currents and diminishing their resistance, we are warranted in concluding, that the upper bed of the river will, when the requisite improvements are effected, follow down the depression at the outfall, and in the lower portions, just as we have seen a similar result ensue in the Wear, as mentioned in p. 88. In this case, the bed of the river in the district under consideration, in order to maintain the same relative position with the future, as with the existing bar, must be lowered 5 to 6 feet below its present level, a depression which would nearly double the actual volume of tidal water in this part of the Tyne, assuming the high water line to maintain the same level as at present.

But, we are to enquire, whether impediments exist, the tendency of which is, to prevent the realization of the advantages just mentioned, to the upper tidal district of the Tyne.

A probable point of interference is Tyne Bridge. On a first view, this structure would appear to offer no great amount of resistance, since its water way of 374 feet is quite as much as we find the general width of the river to be from Newcastle Quay to the Gateshead side. But we are also to consider, that the friction surface of a bridge is much greater than that of a plain section: adding together the wetted perimeters of the arches, we find the total to be, at half tide, 774 feet, while the wetted perimeter of a section, off the quay, is only 375 feet, at half tide; the relative sectional areas are, for the river, 4,356 square feet, and for the bridge, 3,447 square feet; and the relative velocities are as 1 for the river, to 1·3 for the bridge. We have then, upon the principles explained in p. 40, the following results at half tide:—

$$\text{River resistance, ...} \quad \frac{375 \times 1^2}{4{,}356} = {\cdot}086 \text{ or } 1$$

$$\text{Bridge resistance,...} \quad \frac{774 \times 1{\cdot}3^2}{3{,}447} = {\cdot}380 \text{ or } 4{\cdot}4$$

So that the resistance of the bridge is nearly 4½ times as much as that of a plain section of the river off the middle of the quay.

This, it must be admitted, is a considerable difference; yet even the best constructed bridges, provided they have several arches, oppose from two to three times the resistance of an unencumbered section. New London Bridge has, at half tide, a water way of 692 feet, a wetted perimeter of 1,125 feet, and a water way section of 8,304 feet; a relative velocity of 1·6, that of the river being 1, while the river section at half tide is 12,550. Dealing with these figures in the manner before shewn, we shall find that the relative resistance of this bridge to that of the river section, is nearly as 4 to 1, which is not materially different from the proportions above shewn for Tyne Bridge. Our ideas on this part of the subject may be enlarged by making a similar calculation for old London Bridge at the same period of tide. The water way of that ancient structure was 337 feet, the wetted surface 1,745 feet, the water way section stated to be 4,371 feet, but really not more than 4,000; the velocity compared with that of an adjacent river section as 1 to 3, and the magnitude of the river section 12,550; making use of these numbers as before, we find that the resistance of old London Bridge was, to that of the river section, as 47 to 1, which is nearly 11 times greater than that of Tyne Bridge, relatively to the magnitude of each river.*

While, therefore, it must be admitted that Tyne Bridge is, in its present state, an obstacle to the improvement of the river, it is not an impediment of such magnitude as to be a prominent object to the Commissioners, at the outset, at all events, of their labours. Yet, as a natural consequence of that improvement, the period must be looked forward to, when an additional depth of water and demand for larger craft in the upper tidal district, will render great alterations necessary in the structure of the present bridge.

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* At high water, the sectional area of the Thames, adjacent to London Bridge, is taken at 19,586 square feet; that of the New London Bridge at 13,148 square feet; that of the Old London Bridge at 7,000 square feet. The latter is stated at 7,360 square feet below Trinity datum, but was really not more than about 7,000 square feet. At half tide, the waterway section of Old London Bridge was computed at 4,371 square feet, but would not probably exceed 4,000 square feet.

I have put the above calculations in their simplest form, by regarding the question as a comparison of the resistance arising from friction; in other words, by considering a bridge as a structure which, for a short distance, divides a river into several separate streams. But in this, as in other examples of the motion of fluids, there are complex circumstances, arising from changes of direction, effects of eddies, cross currents, &c., constituting, as we may say, *unknown quantities* in the present state of fluid dynamics, and which, if introduced, would increase the result as against the bridge.

A second impediment exists in the great extent of shoal at the eastern end of the King's Meadows, and the diffusion of the current on both sides of that island; in fact, the whole of this part of the river, for a distance of two miles up to Derwent Haugh, is in a very bad condition, and requires much improvement; its injurious effect upon the still more western districts, admitting of a comparison with that of the Jarrow and Hebburn sands. The lines laid down here on the parliamentary plans would have been to a certain extent remedial; but a really effective improvement would require the river to be confined to a single channel. It is in this locality that the tidal wave, at the first of flood, makes a slower progress than in any other portion of the river.

At Derwent Haugh, the bed of the river suddenly expands. If we put 1 of mean width for the previous 3 miles westward, then the mean width for the next 2½ miles below this point, is nearly 2½. Let us endeavour, the example being a good one, to explain the structure of this part of the bed of the Tyne, upon the principles laid down in the fifth chapter.

The river Derwent, which here joins the Tyne, carries a coarser material than its larger recipient, and is, therefore, enabled, though of much smaller volume, to determine a point in the position of the Tyne, by pressing its bed towards the northern declivity of the valley. But for the operation of this cause, it is not difficult to perceive, from the previous direction of the Tyne, that its course would have been southward, and in all probability, it would have formed a winding in the low grounds of Dunstan Haugh. However, the interference of its affluent, prevents this result from taking place, and obliges the river to take a line of greater fall. Under these circumstances, we have, as a succedaneum for the winding, an enlarged bed, with an extensive shoal, the upper portion of which constitutes the island of the King's Meadows. The reader will here recollect the explanation of the great Lemington Bend, and of the formation of the

Dent's Meadow Island, as soon as the current resumed the line of greatest fall.*

It has been conceived, that a tidal basin in this upper district—a sort of Antipodes to Jarrow Slake—might prove beneficial. Yet no great degree of consideration is required to convince us that such a reservoir could not remain open, but would presently be silted up, and again handed over to the dominion of the river. And here the argument may fairly end, the proper situation for such a receptacle being manifestly the bed of the river itself, where, by the construction of suitable works, it can be kept open, and where also it possesses the greatest practical amount of utility; for assuming the bed to be in this condition, it is obviously no longer necessary to have such a reservoir as the one under consideration.

In improving the upper portions of the river it will be necessary to proceed with caution near the lower limits of the gravel, and perhaps it would scarcely be judicious in the first instance at least, to make those restrictions above Newburn, which by increasing the energy of land floods, may have the effect of bringing the gravel down to the navigable districts. It is not meant by this, that no alterations are to be made westward of Newburn Haugh, but it would be right at all events, to establish improvements in the lower portion of the river before interfering with those where the bed undergoes so material a change as that of a transition from sand to gravel.

It was my intention to have gone more into detail regarding the improvements of this portion of the river, but the subject cannot be exhausted at once, and this memoir has already expanded far beyond my original intention. I shall therefore conclude by recapitulating the improvements suggested to be made, with their expected results.

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* We thus perceive the accuracy of Dubuat's observation, "La proprieté qu'a une riviere de former des îles est un marque de la grandeur de sa pente, et vient principalement du manque d'exáctitude dans le tracé des sinuosités."

1. The Piers proposed at the outfall of the river are expected to increase the depth of water at the entrance, from 7 to at least 12 feet, at low water in spring tides. Such a result we may not be esteemed rash in calculating upon, considering the additional and sustained scouring agency that will be imparted to the tidal currents, and especially to the land floods: the velocity of the latter in conjunction with the ebb tide, being sometimes upwards of 6 miles an hour in the lower portions of the river.

2. On the map B, proposed improvement lines are drawn from Willington and Jarrow Quays eastward, being that portion of the river which is assumed to remain open for alteration. By those lines it is intended to inclose Jarrow Slake, as well as the Coble Dean indentations: and these and all other spaces thus detached, are meant to be shut off from the river by means of solid quaying or embankment raised above the level of the highest waters.

3. By carrying out the designs mentioned under heads 1 and 2, it is expected that the present bed of the Tyne below bridge, will be depressed to the average extent of at least 5 feet; and the extension of a system of improvement, based on similar principles, to the upper tidal district, will, it is reasonable to anticipate, produce corresponding effects in that portion of the river.

THE END.

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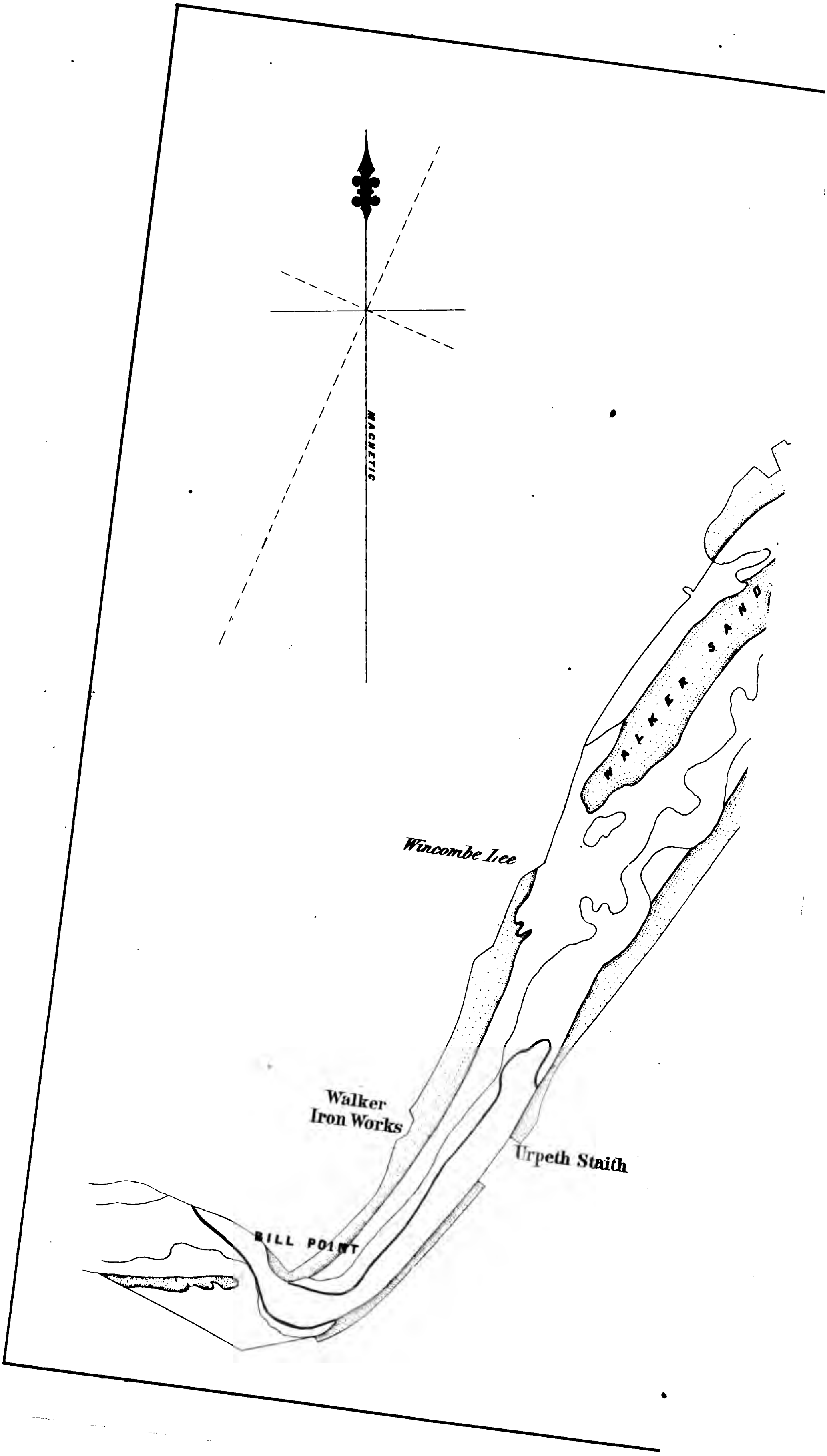
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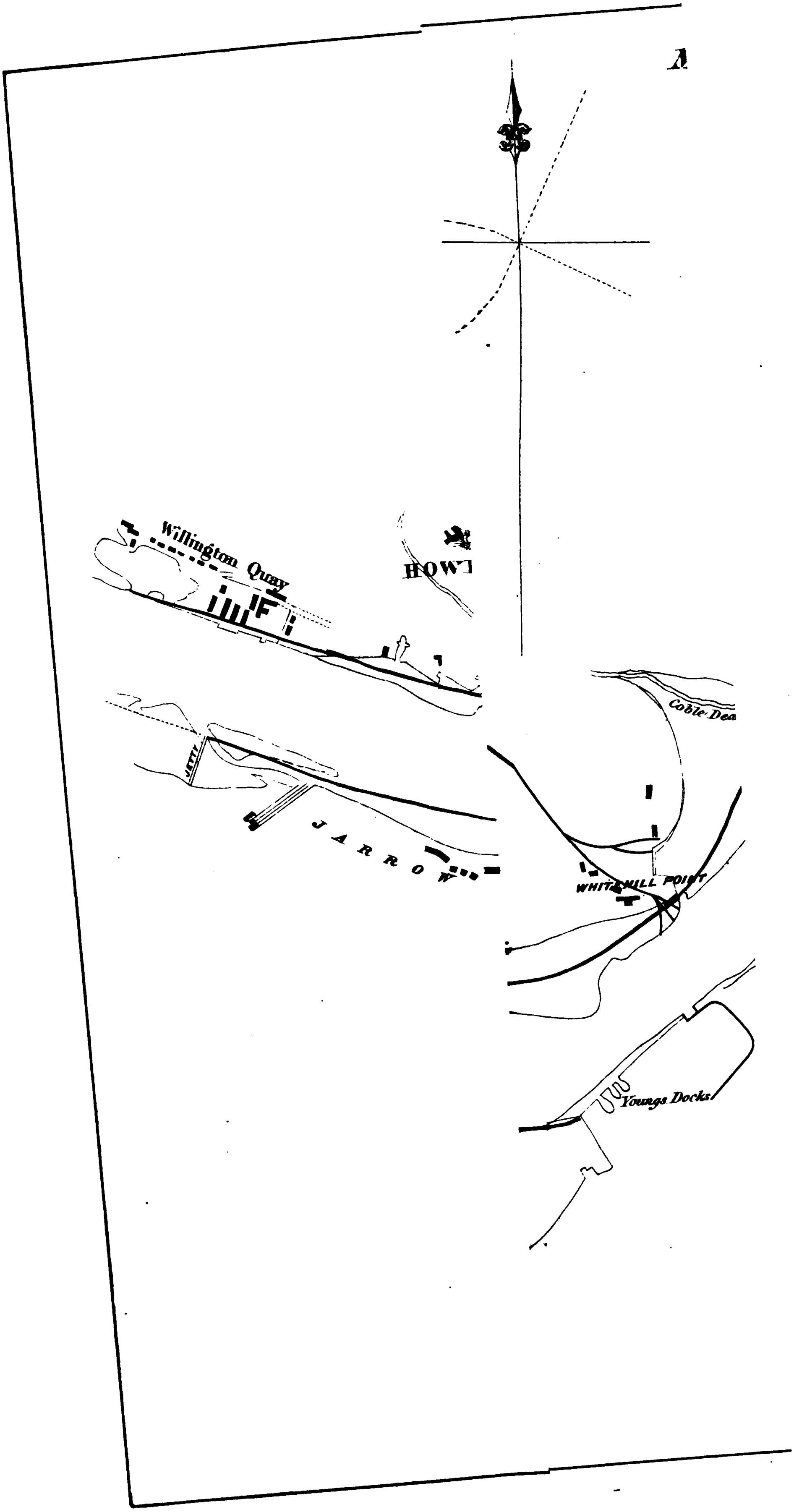
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